

Processes shaping the surface radiation budget in West Africa observations versus CMIP5 models

Françoise Guichard

Thanks to

Laurent Kergoat and Eric Mougin (GET/OMP, Toulouse)

Observations of the AMMA-Catch Sahelian sites in Mali

(multi-year surface meteo and radiative flux measurements over different surface types)

Dominique Bouniol and Fleur Couvreur (CNRM-GAME, Toulouse)

Frédéric Hourdin (LMD/IPDL, Paris)

*Focus on surface fluxes
And on the Sahel*



Contexte

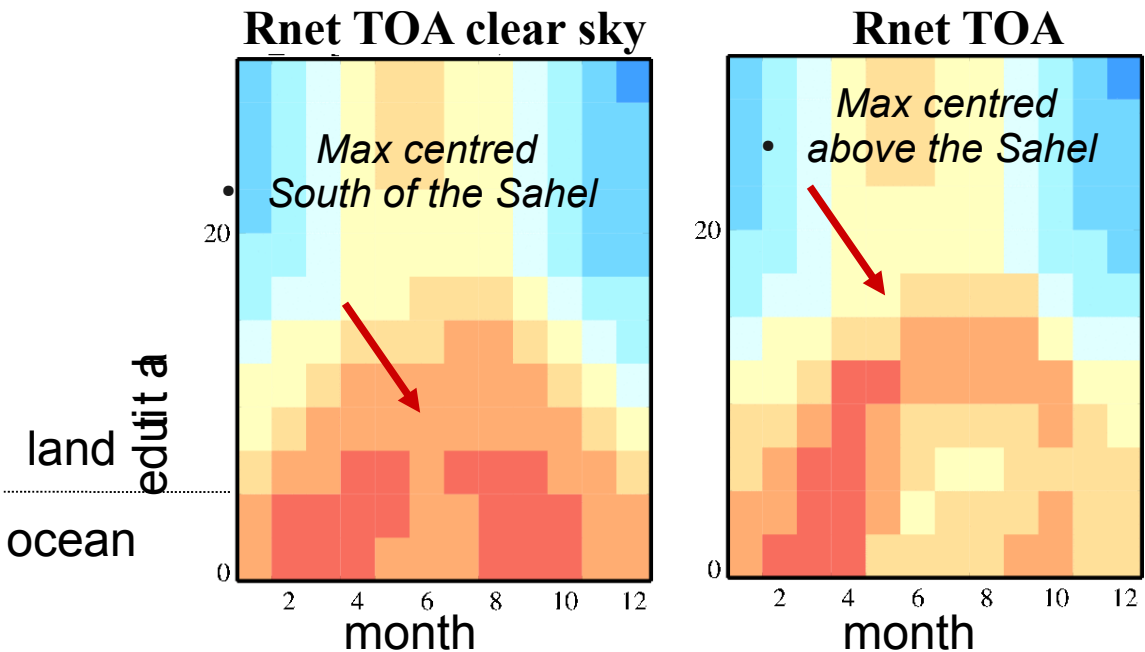
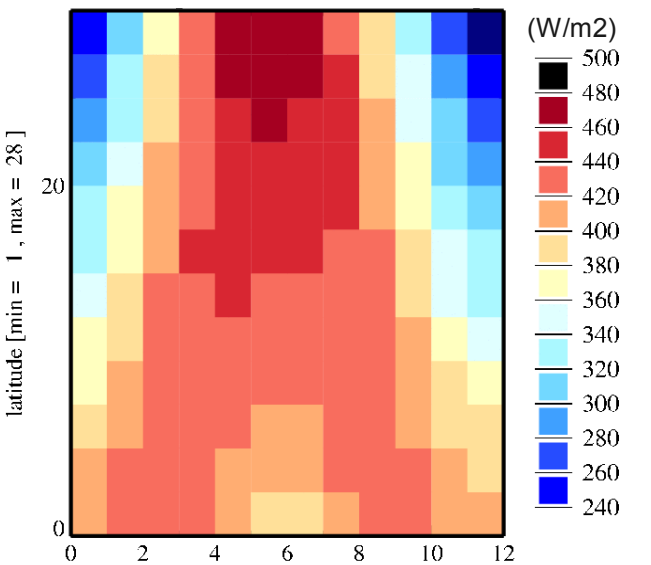
A complicated radiative budget, strongly shaped by physical processes, at the surface and in the atmosphere, involving water vapour, aerosols, clouds and precipitation

With a significance at different space and time scales: from local to regional, from diurnal to interannual

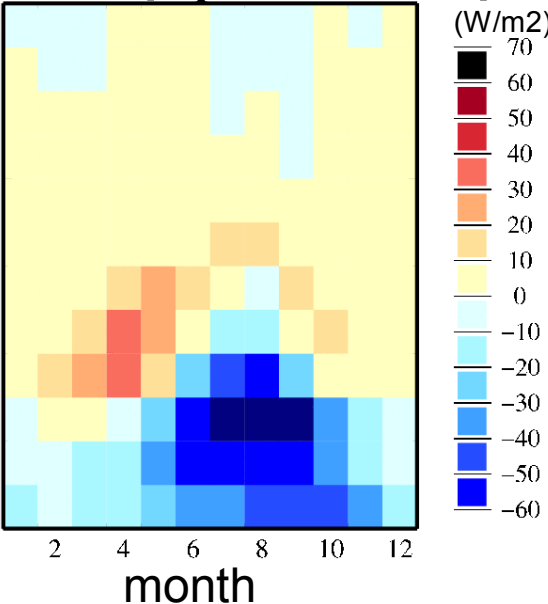
Critical for the energetic of the monsoon (Charney 1975, Eltahir and Gong (1996)... still an issue in 2014, with consequences on modelling (forecast, climate)

ANNUAL CYCLE AT TOA

SWin TOA



Cloud impact TOA



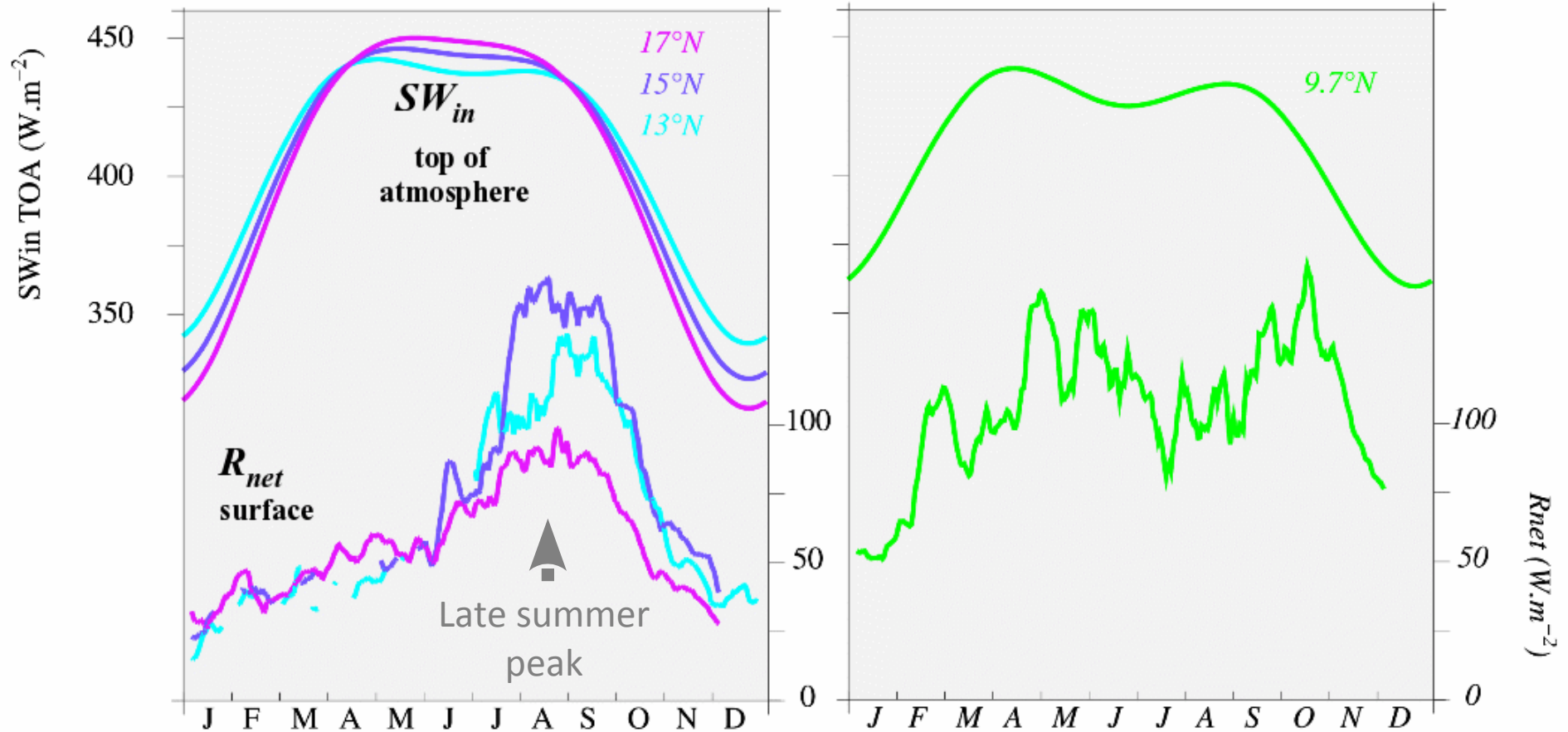
distinct cloud rad. impact with latitude, favouring convection northwards (Chou & Neelin 2002: more Rnet TOA favours more convection)

CERES, avg [10°W,10°E]

ANNUAL CYCLE AT THE SURFACE

In the Sahel (semi-arid)

In the Soudanian region (wet Tropics)



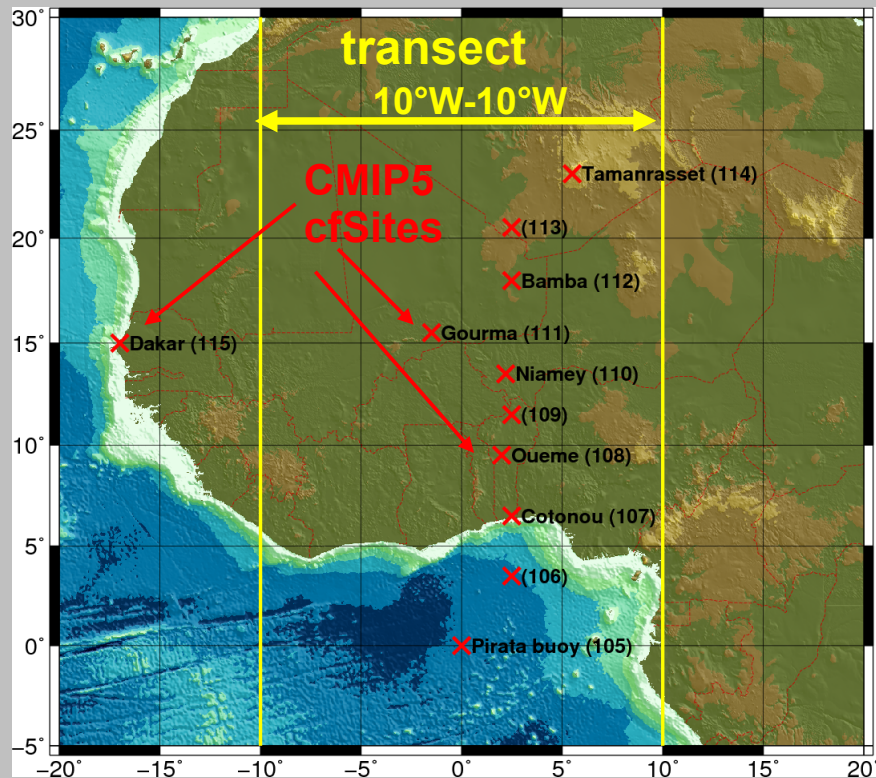
A surface energy budget involving a series of processes

Surface : T_{sol} , soil moisture, vegetation

Atmosphere: water vapour, clouds and aerosols

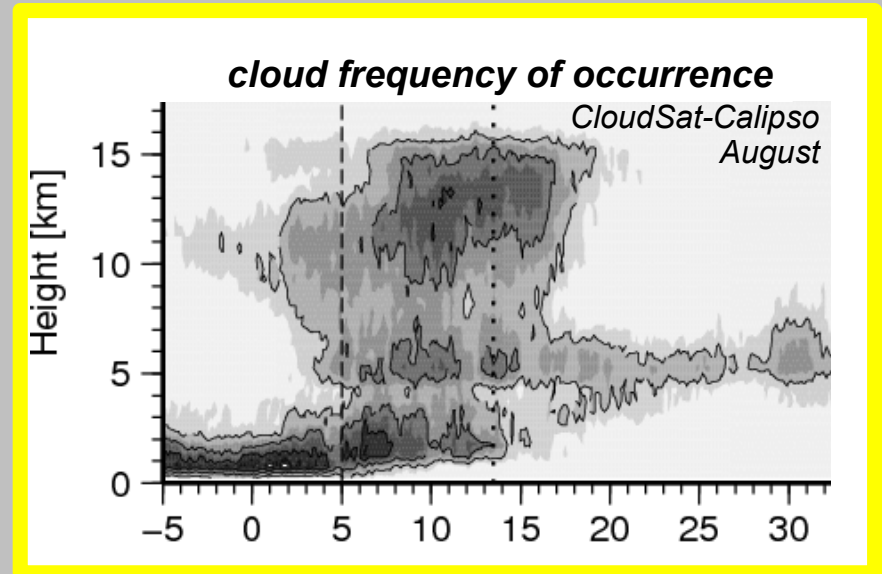
couplings between the energy and water cycle (rainfall)

Complementarity of meridional transect and local sites (for analysis & eval models)



S-N TRANSECT: take advantage of the large-scale climatological gradient

AMMA-MIP: Hourdin et al. (2010)



Bouniol et al. (2012)

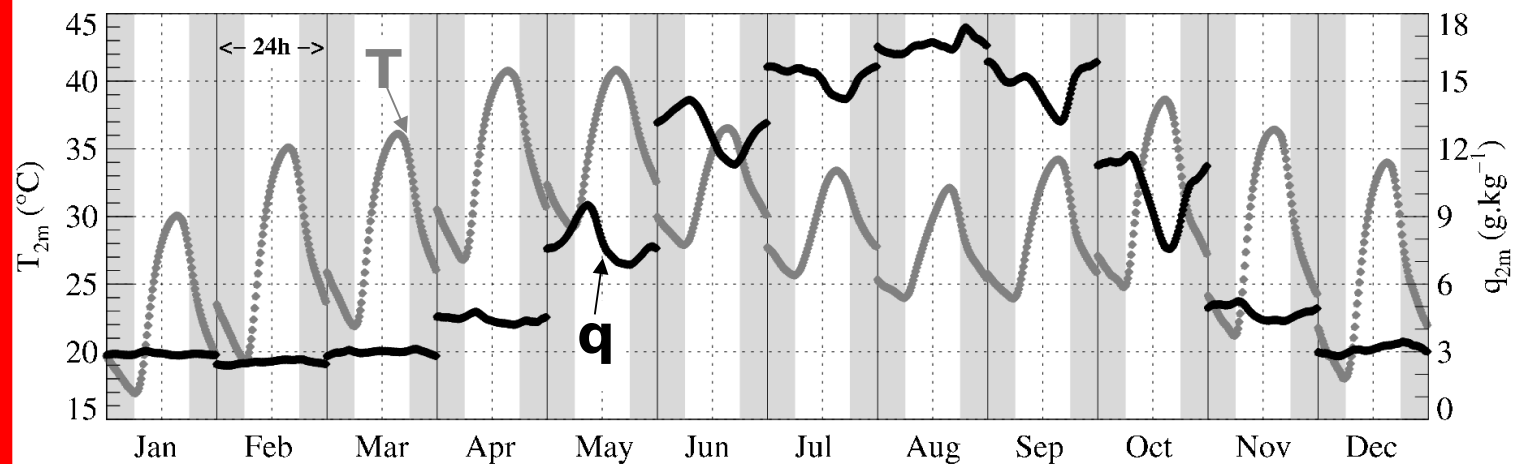
CMIP5 cfSites

sample meridional gradient

locations where ground data available

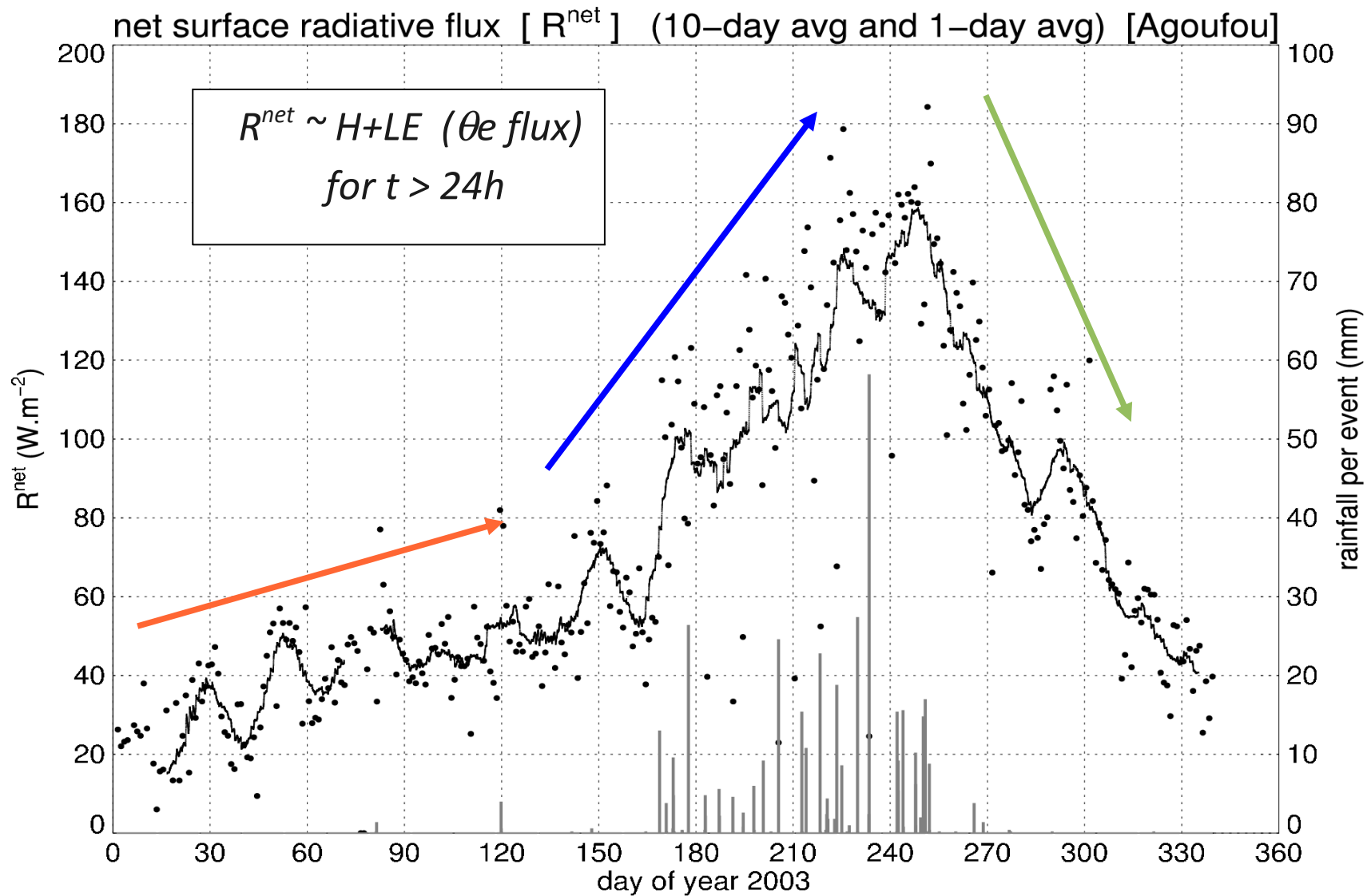
AMMA-CATCH high-frequency long term observations (~ 10 years), ARM Niamey 2006

Sfc AWS T_{2m} , q_{2m} : monthly-mean diurnal cycles [Agoufou]



Guichard et al. (2009)

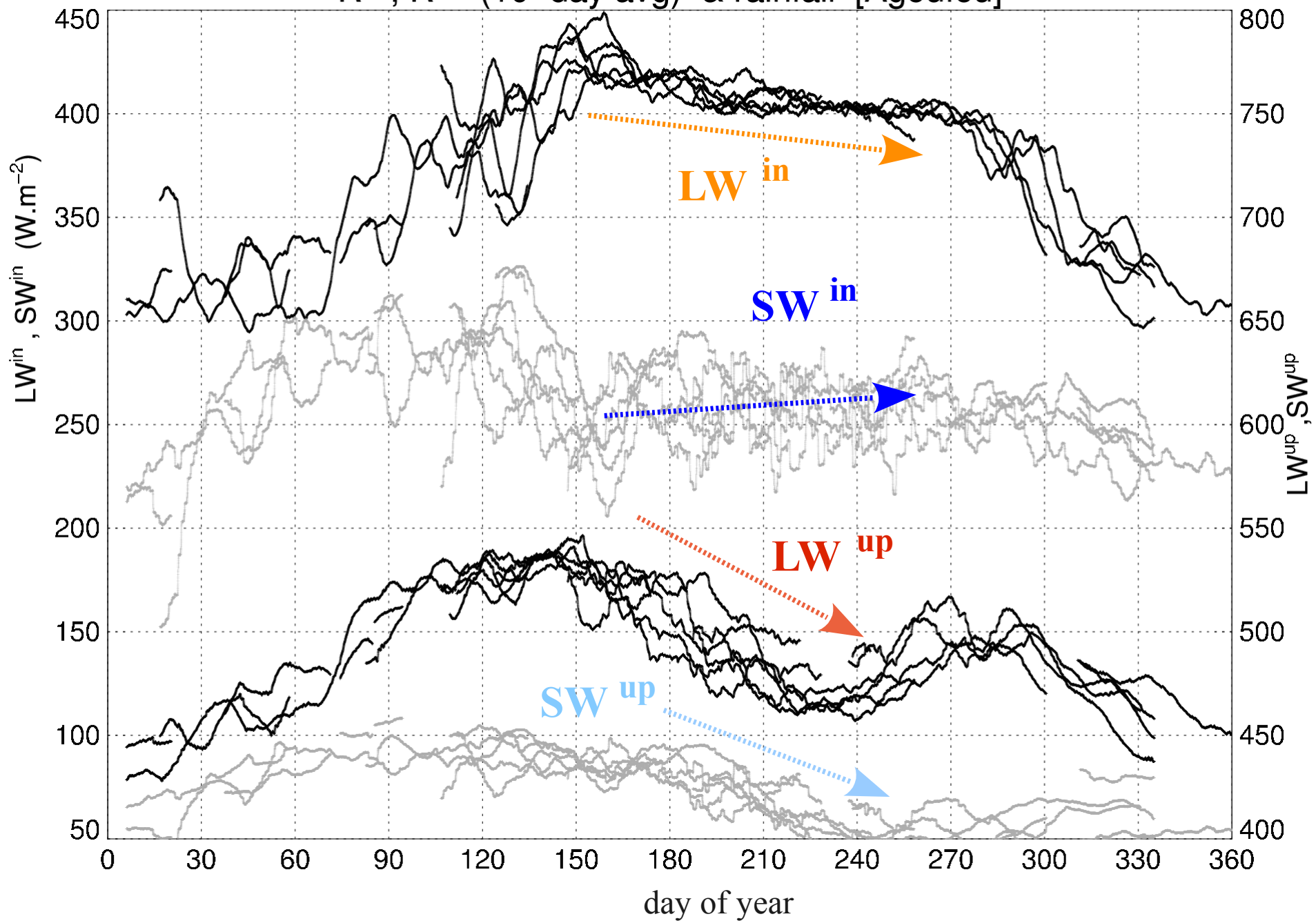
seasonal cycle of surface radiative fluxes : R^{net}



Large fluctuations of R^{net} , increase sharper in Summer than in Spring

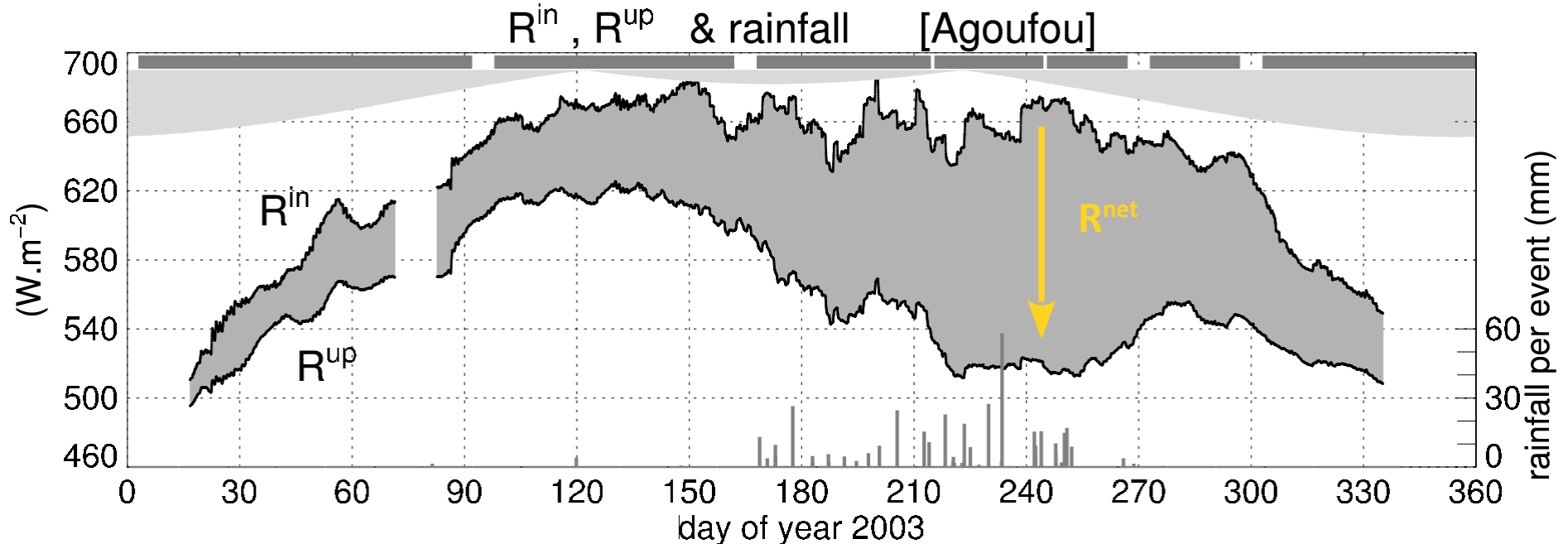
Decomposition of radiative fluxes

R^{in} , R^{up} (10-day avg) & rainfall [Agoufou]



seasonal cycle of surface radiative fluxes

$$R^{\text{net}} = R^{\text{in}} - R^{\text{up}}$$



Guichard et al. (2009)

R^{net} changes mainly driven by the decrease of R^{up} from June to mid-September

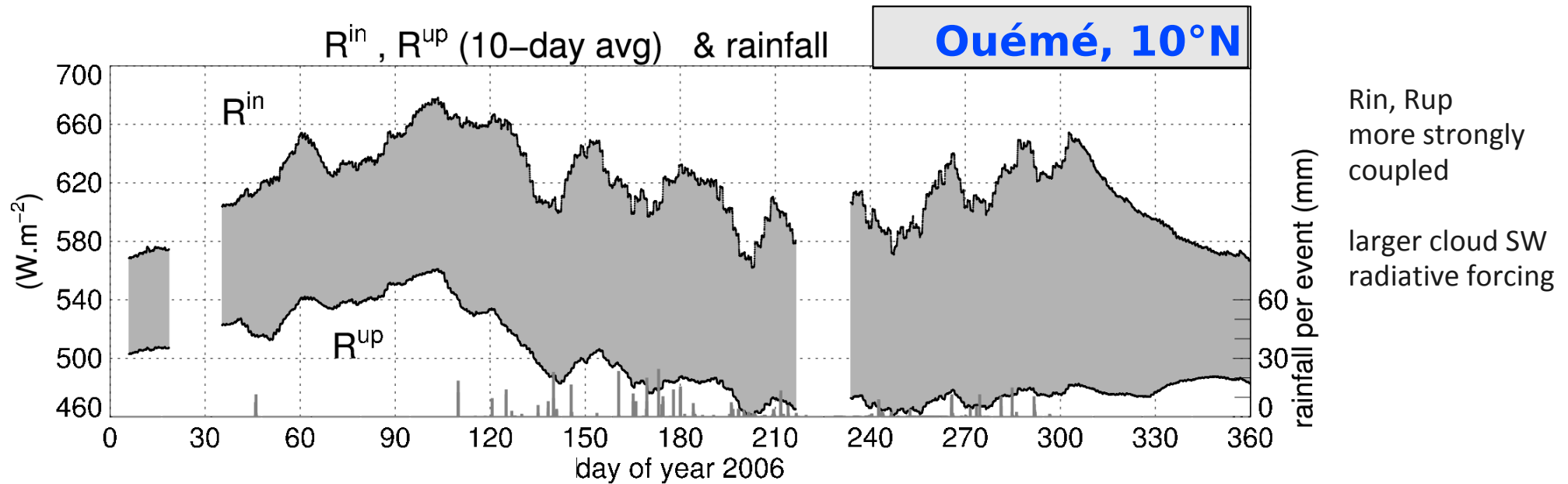
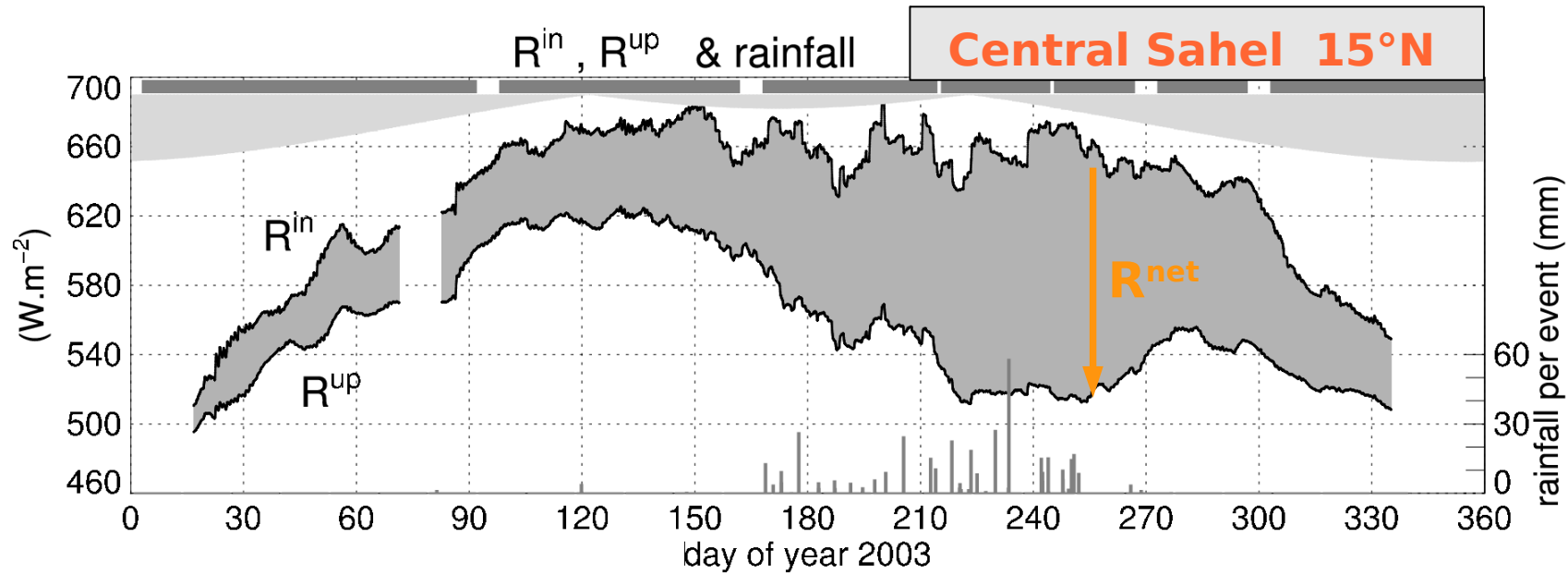
surface cooling

surface albedo
(veg, Samain et al. 2008)

consistent with results of Slingo et al. (2009) & Ramier et al. (2009) in Southern Sahel

- *does not mean that aerosols & clouds do not matter!*
e.g. reduction of SW^{in} by clouds and aerosols $\sim 25\%$ in July-August
(more by Olivier Geoffroy, next talk)

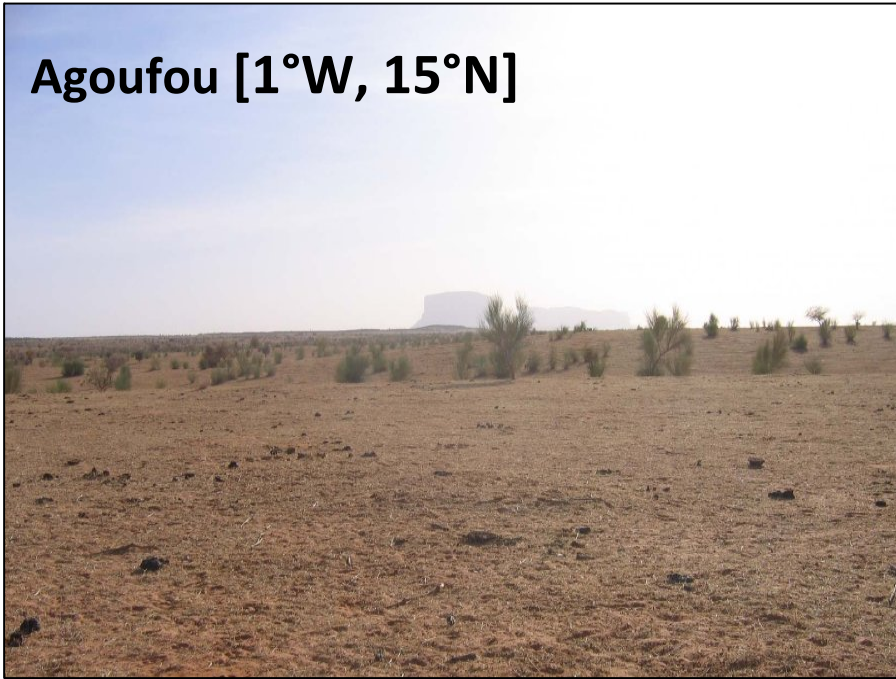
Meridional contrasts in surface-atmosphere radiative exchanges



Sahelian Gourma site, Mougin, Hiernaux et al.

Agoufou [1°W, 15°N]

*dry
season
(March)*



**Accacia forest
[1°W, 15°N]**

Agoufou

*monsoon
(August)*

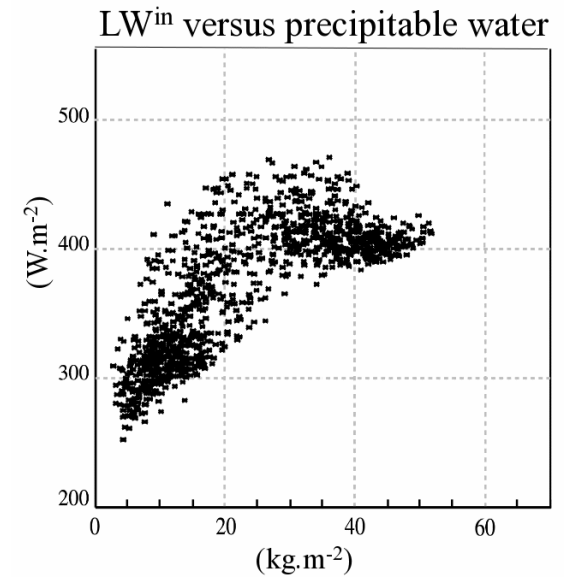
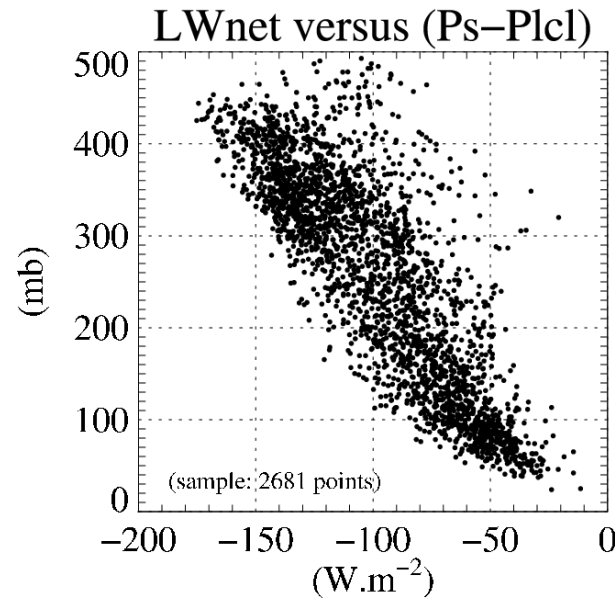


Accacia forest

photos accacia site & dry season V. Le Dantec

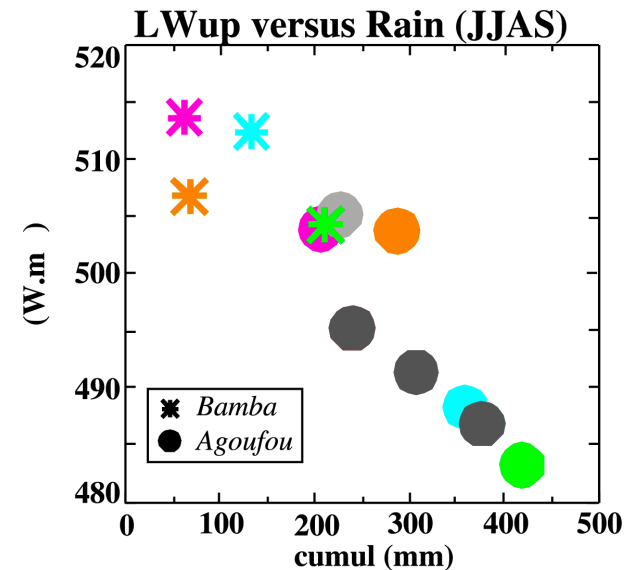
Couplings between LW radiative fluxes and thermodynamics

Daily values
(Jan to Dec)

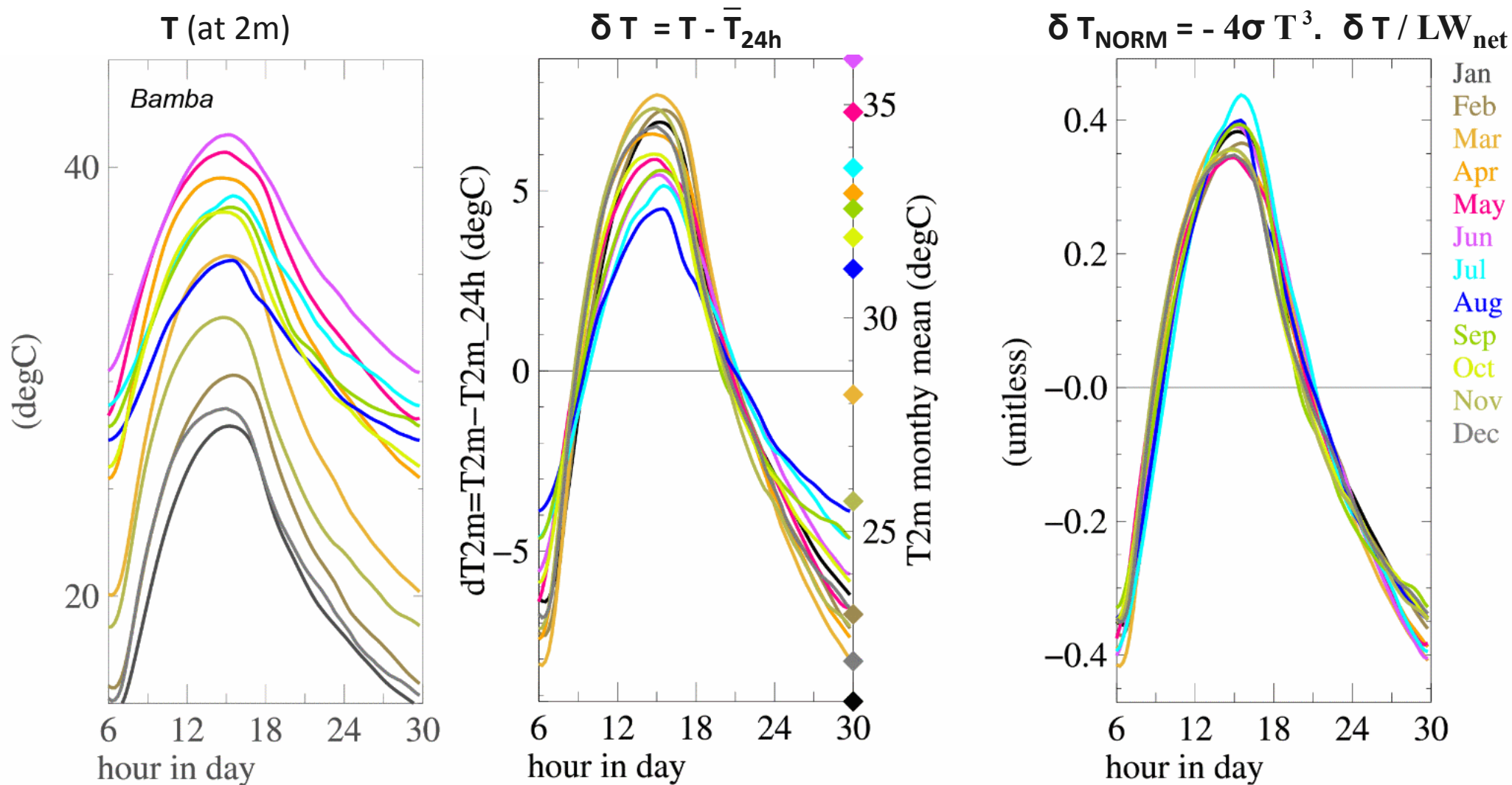


Interannual variability, monsoon season

*(short) interannual variability of R_{net}
mostly explains by LW_{up}*



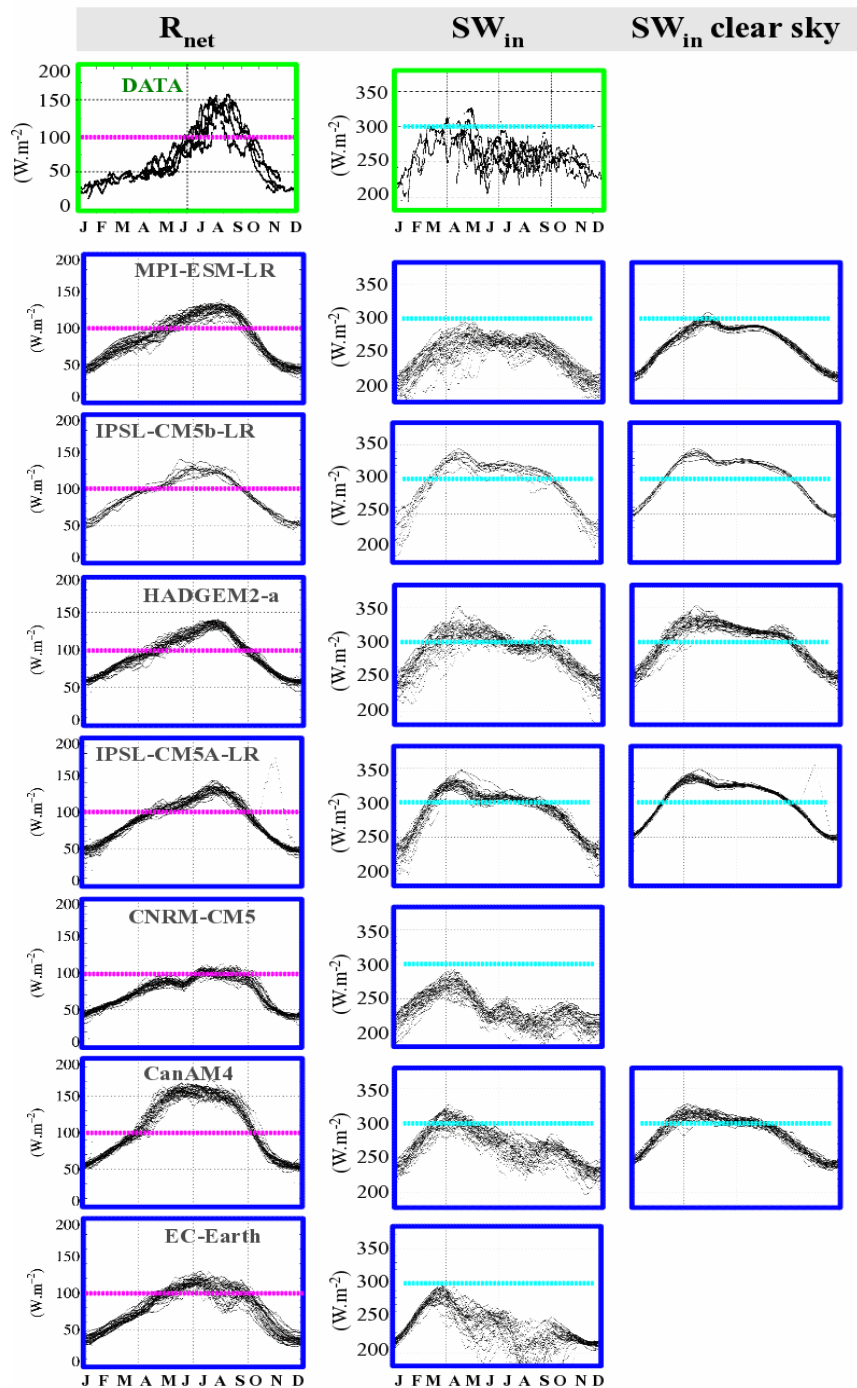
Couplings between LW radiative fluxes and thermodynamics



$$DTR_{\text{Rad}} = -4\sigma T^3 / LW_{\text{net}}$$

(following Betts 2006)

Annual cycle of surface radiative fluxes



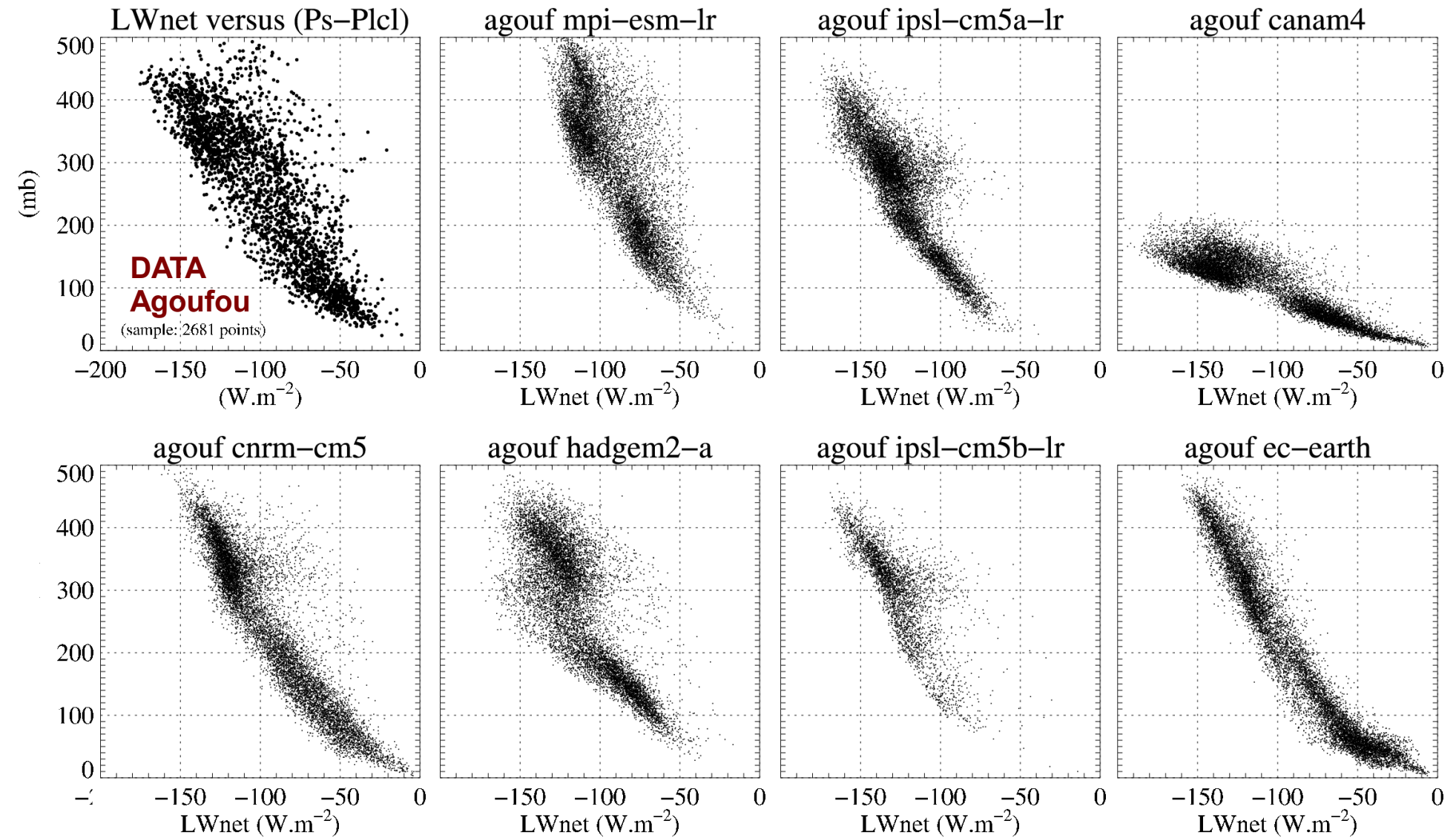
CMIP5 AMIP runs (~ 30 years)

example in the Sahel:

Agoufou CMIP5 cfSites point annual cycle

- * R_{net} : distinctive > 0 bias in Spring
 - * Much larger spread, and errors among models in surface incoming radiation SW_{in} than in surface net radiation R_{net}
 - * Sfc R_{net} \sim OK does not mean at all that sensible and latent heat fluxes !
 - * Large differences of SW_{in} even without clouds! (aerosols)
- Such biases induce errors in the surface energy budget, possibly convective events strength...
(very large spread in reanalyses too)*

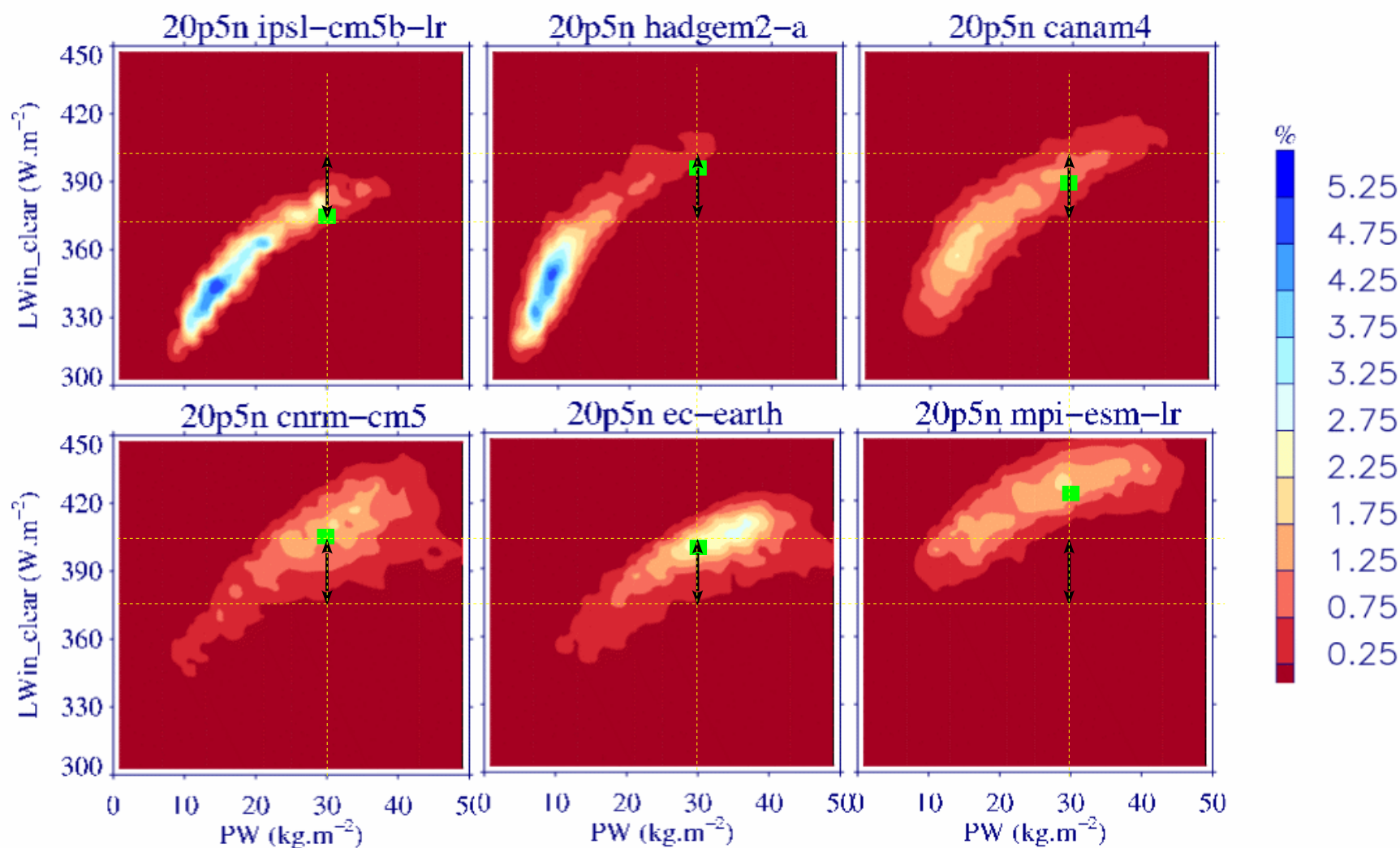
Couplings between surface LW_{net} and P_{lcl}



Couplings in observations and CMIP5 runs, but with large quantitative differences
Same result for the other AMMA-CATCH sites

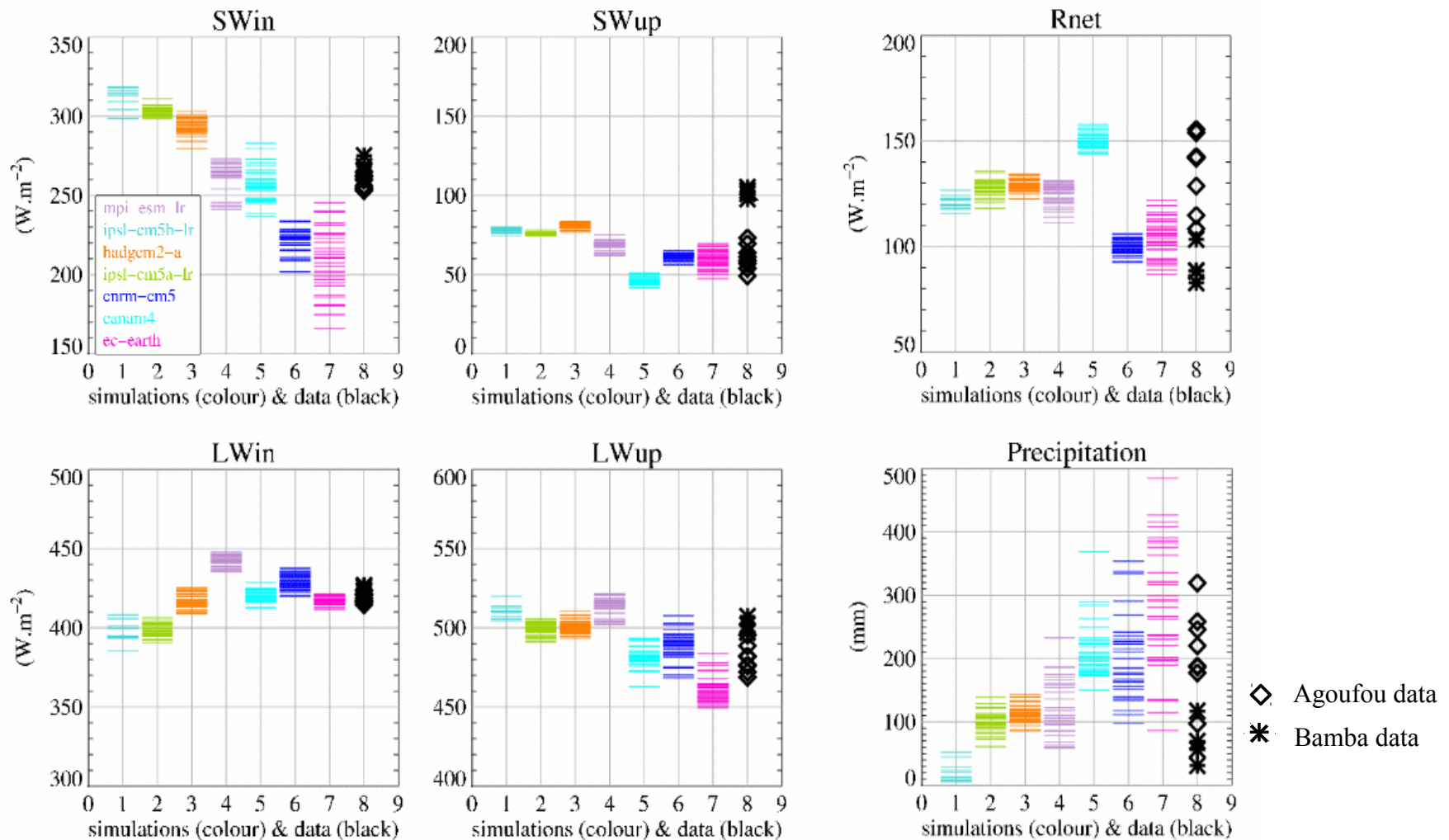
Couplings between surface LW_{in} clear sky and precipitable water

Joint PDF (precipitable water, surface LW_{in} clear sky)
CMIP5 amip runs (30 years), daily values at $2^{\circ}E$, $20.5^{\circ}N$



surface radiative fluxes during the monsoon

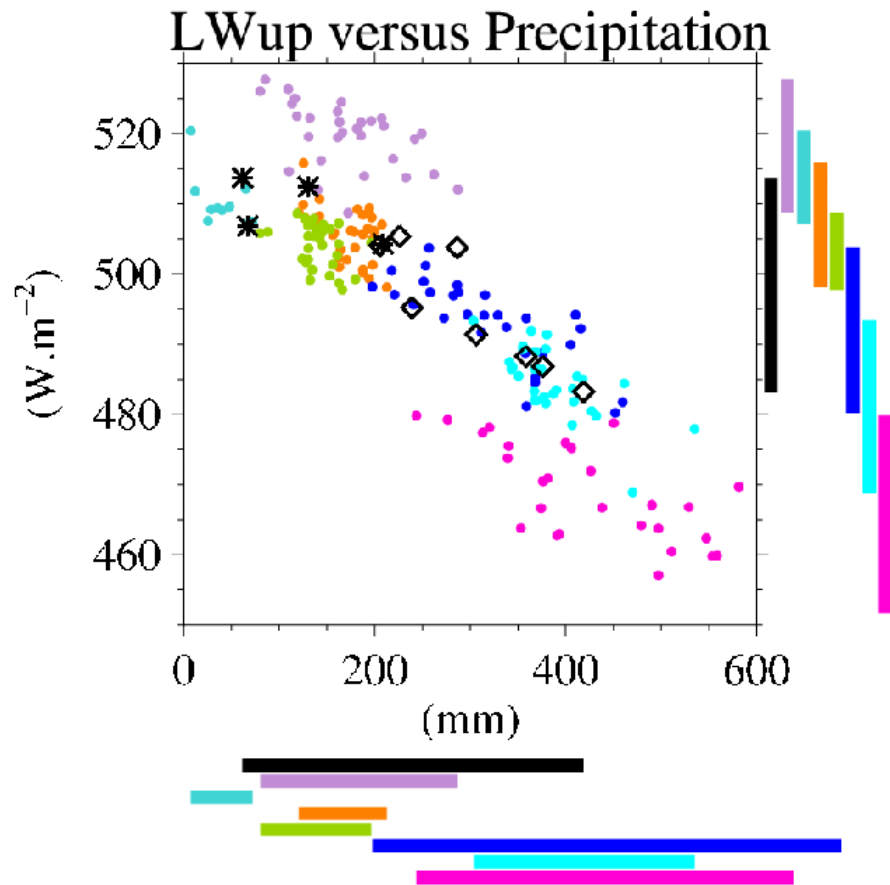
Agoufou cfSites point, core monsoon (Jul-Aug average)



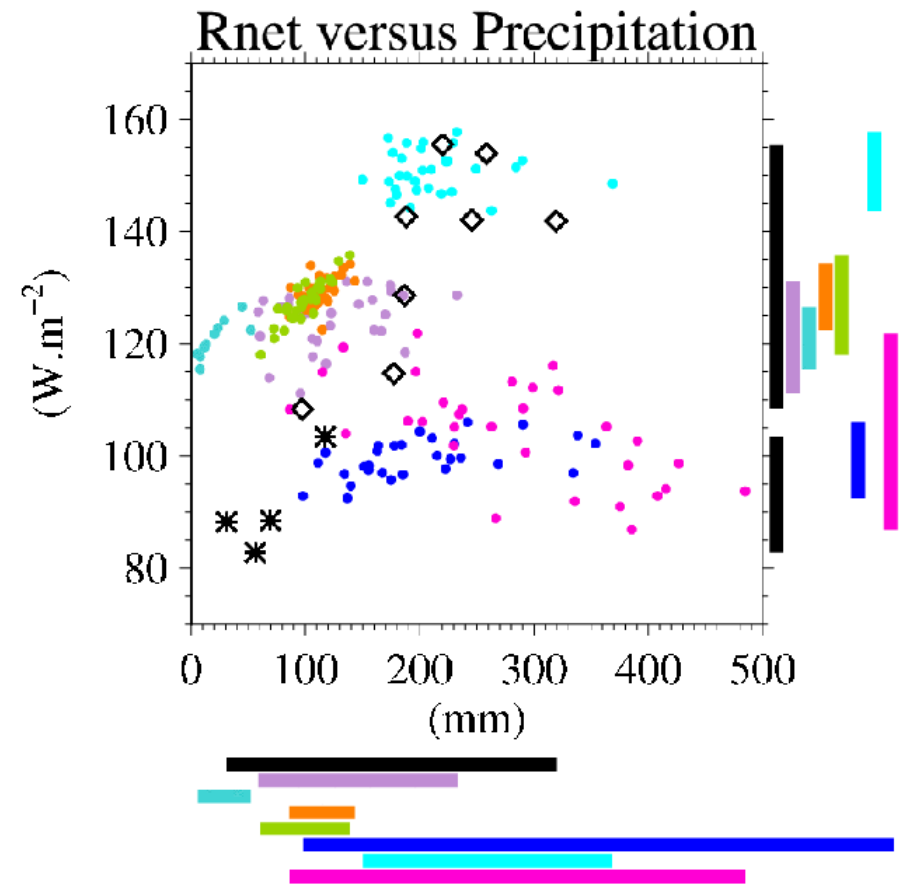
(one tick=1 year, one color= one model, obs in black, 2 sites to sample range of precip amount and their differences in obs and models)

Couplings between surface radiative fluxes and precipitation

Agoufou cfSites point, core monsoon (Jul-Aug average)



Spread among model in simulated LWup strongly related to precipitation spread



Beyond mean differences, most models do not simulate an increase of Rnet with precipitation

Summary

Process-based analyse of surface data (energy budget, radiative fluxes, meteo, thermodyn)

Use of high-frequency long term observations sampling West Africa from the Soudanian region (wet Tropics) to Northern Sahel (semi-arid)

- * stress the importance of distinct physical processes along the annual cycle (large amplitude of SEB in the Sahel)
- * Couplings between water and energy cycles
- * Couplings between radiation (LW), thermodynamics and clouds (+ aerosols)
- * guidance for modelling and evaluation of models
- * evaluation of satellite and reanalyses products (*Kergoat, Ramier et al.*)

Evaluation of climate models

- * Very large errors in all components of surface radiative fluxes
- * Very large spread in SWin, even in clear sky (several tens of W.m^{-2})
- * Broadly similar couplings compared to observation, but qualitatively only
- * Spread in the relationships not all explained by differences in precipitation (involve large differences in albedo, cloud radiative impact, representation of aerosols)

Work ongoing to precise cloud radiative forcing at the surface:

by cloud type, environmental regime, documentation of diurnal timing

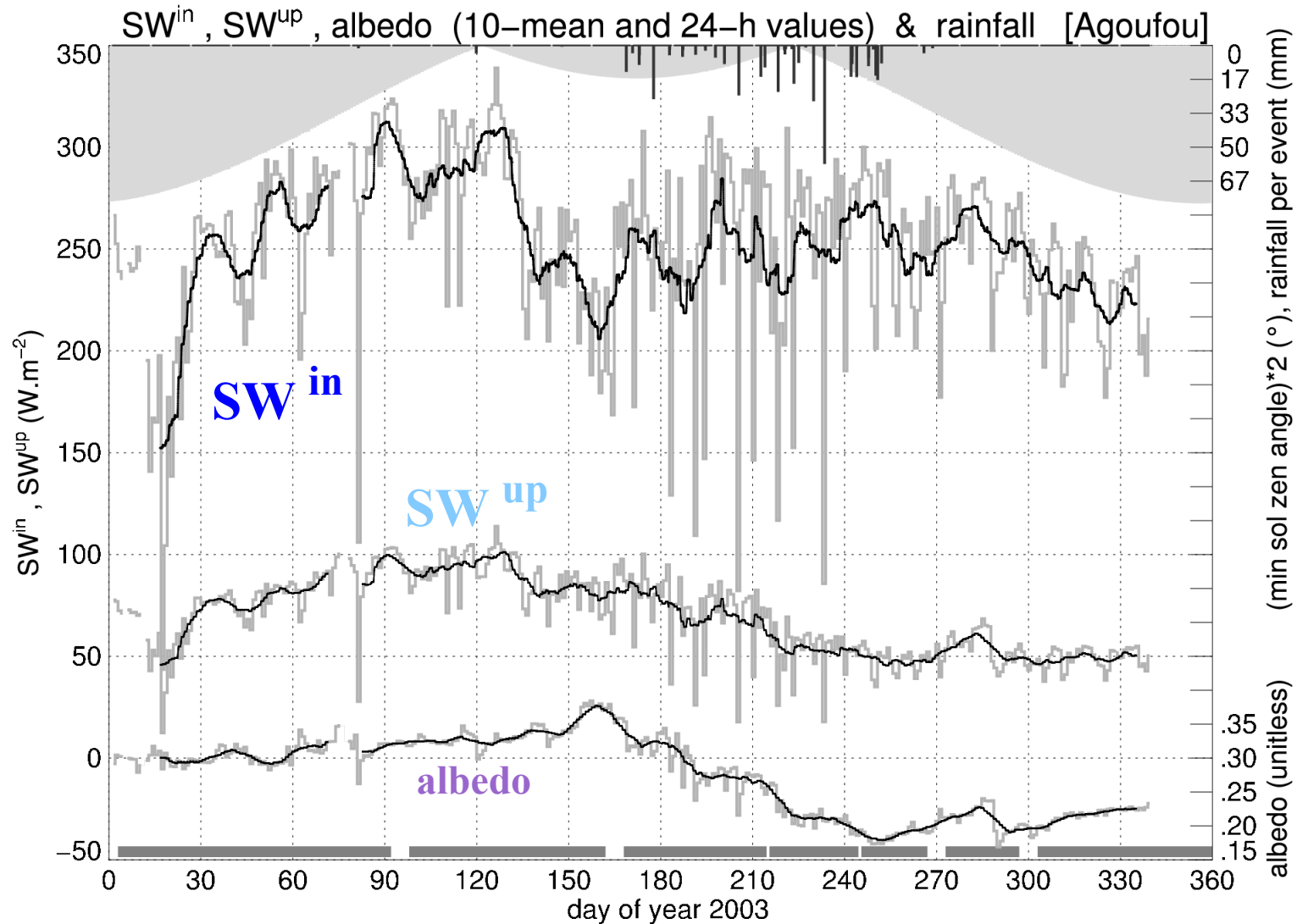
Explore possible links between cloud types, cloud radiative forcing and radiative biases

Extend more systematically diagnostic analyses (identification of couplings) to all sites

Links between spread in climate and climate sensitivity in models?



seasonal cycle of surface radiative fluxes : SW

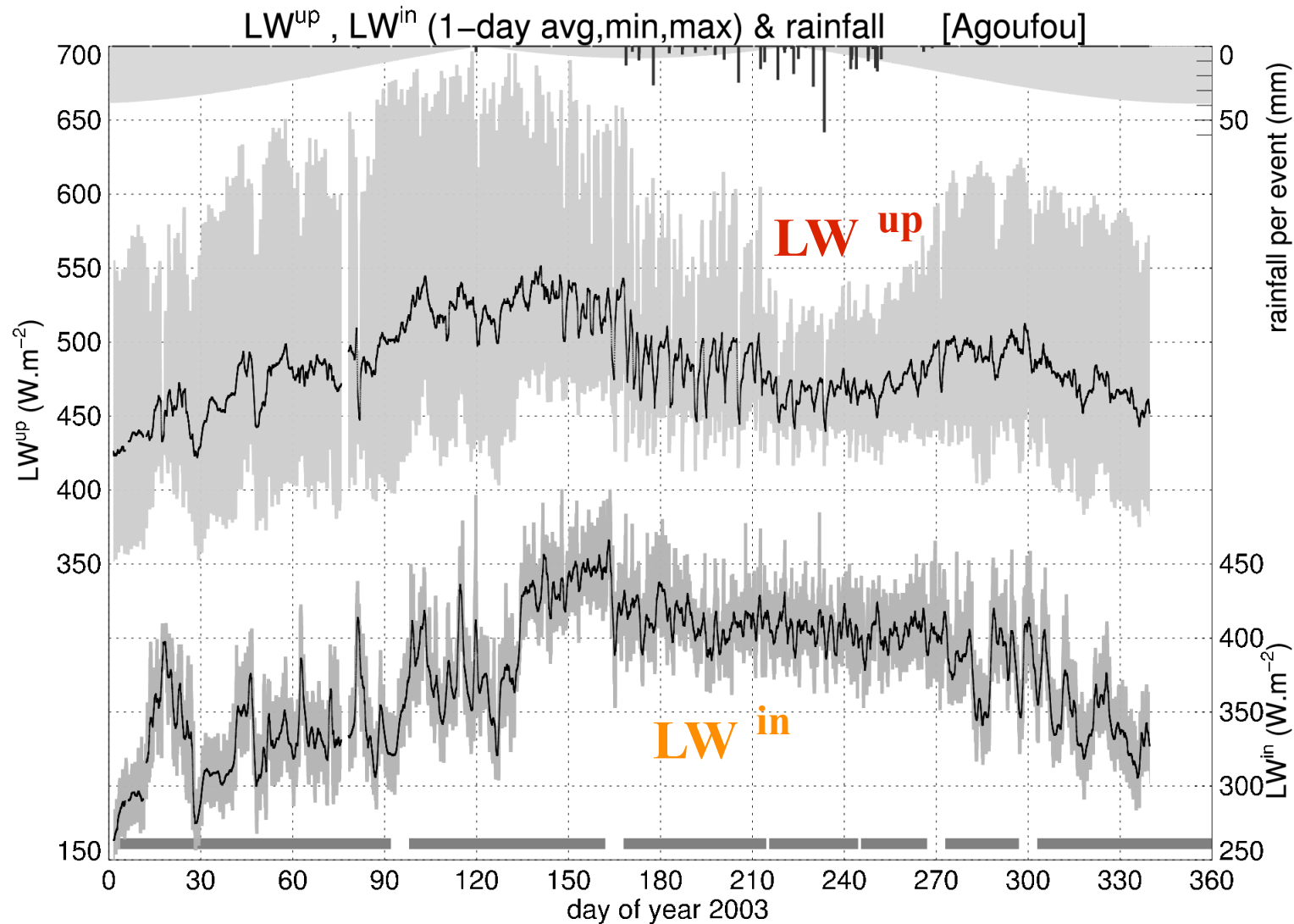


- strong fluctuations of SWⁱⁿ distinct from those of R^{net}, minimum in June prior to rainfall
- SW^{up} does not follow the same evolution as SWⁱⁿ

drop of the albedo during the monsoon (0.35 to 0.2) [linked to vegetation, consistency of local data with MODIS at larger scale in the Sahel, Samain et al. 2008]

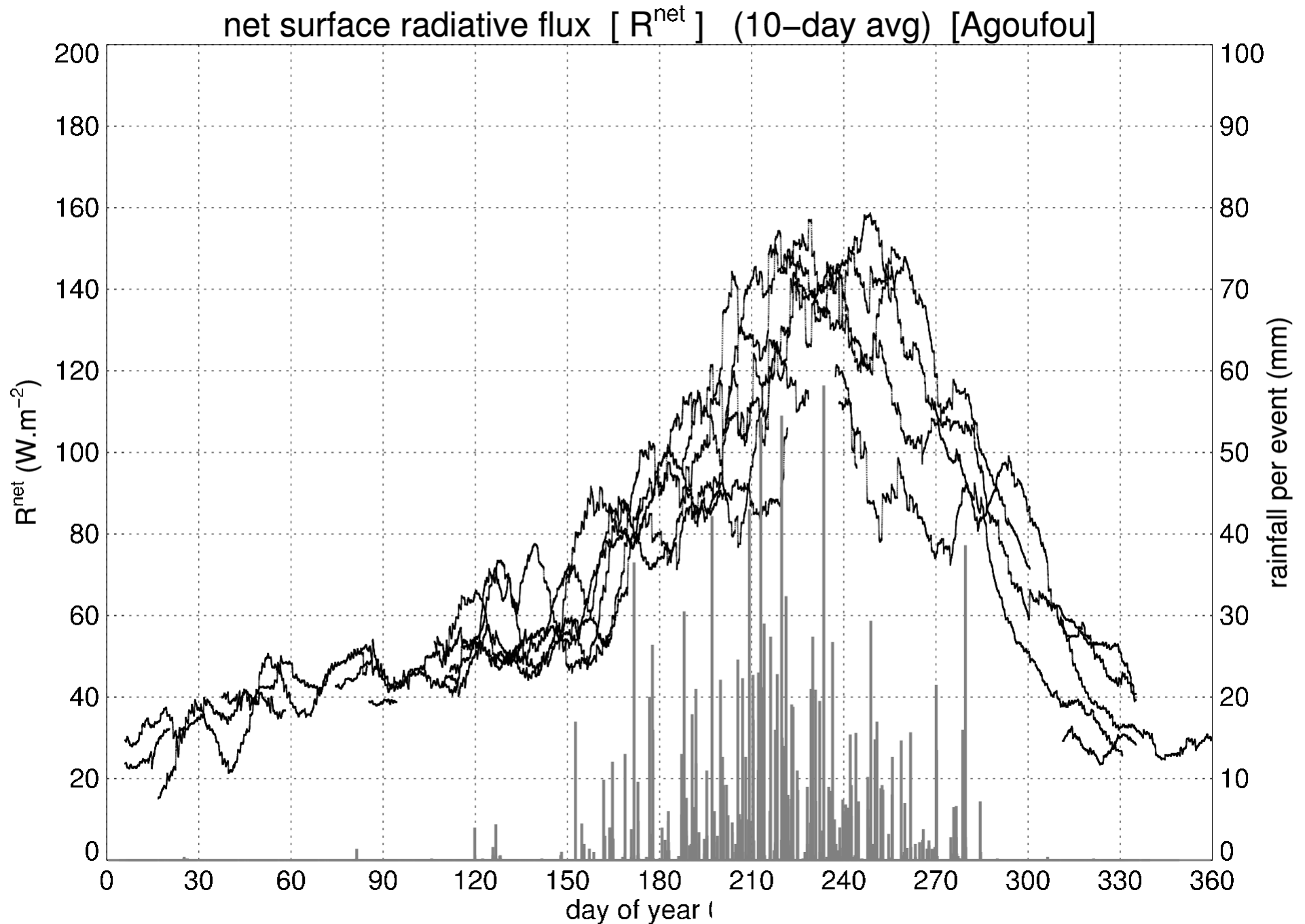
fluctuations of albedo fct(spectral composition of Swⁱⁿ) - aerosols & water vapour

seasonal cycle of surface radiative fluxes : LW



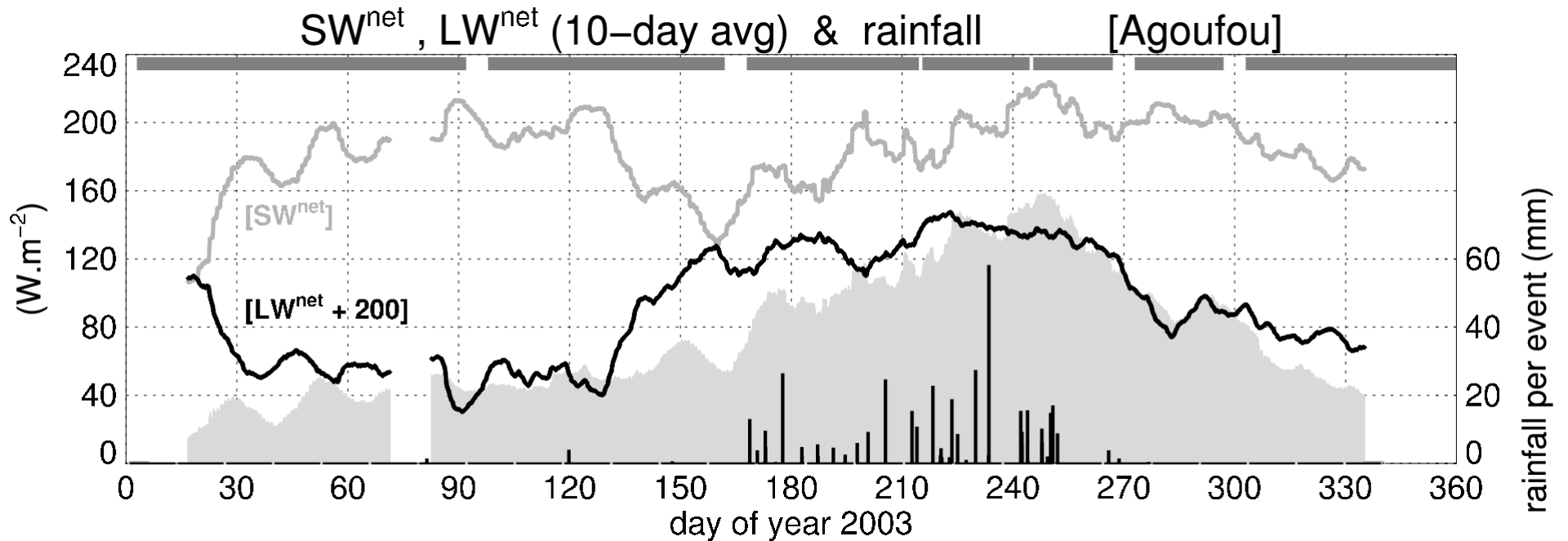
- close evolutions of LW^{up} and 2m-temperature
- in June, max of LWⁱⁿ, when SWⁱⁿ is min (atmosphere warmer & more opaque)
- LWⁱⁿ decreases from June to Sept while qv, RH, PW increases & clouds are more numerous (*not so intuitive, involves an atmospheric cooling*)

Interannual variability of radiative fluxes (coupling with rainfall)



seasonal cycle of surface radiative fluxes

$$R^{\text{net}} = LW^{\text{net}} + SW^{\text{net}}$$



partial balance between net LW & SW fluctuations

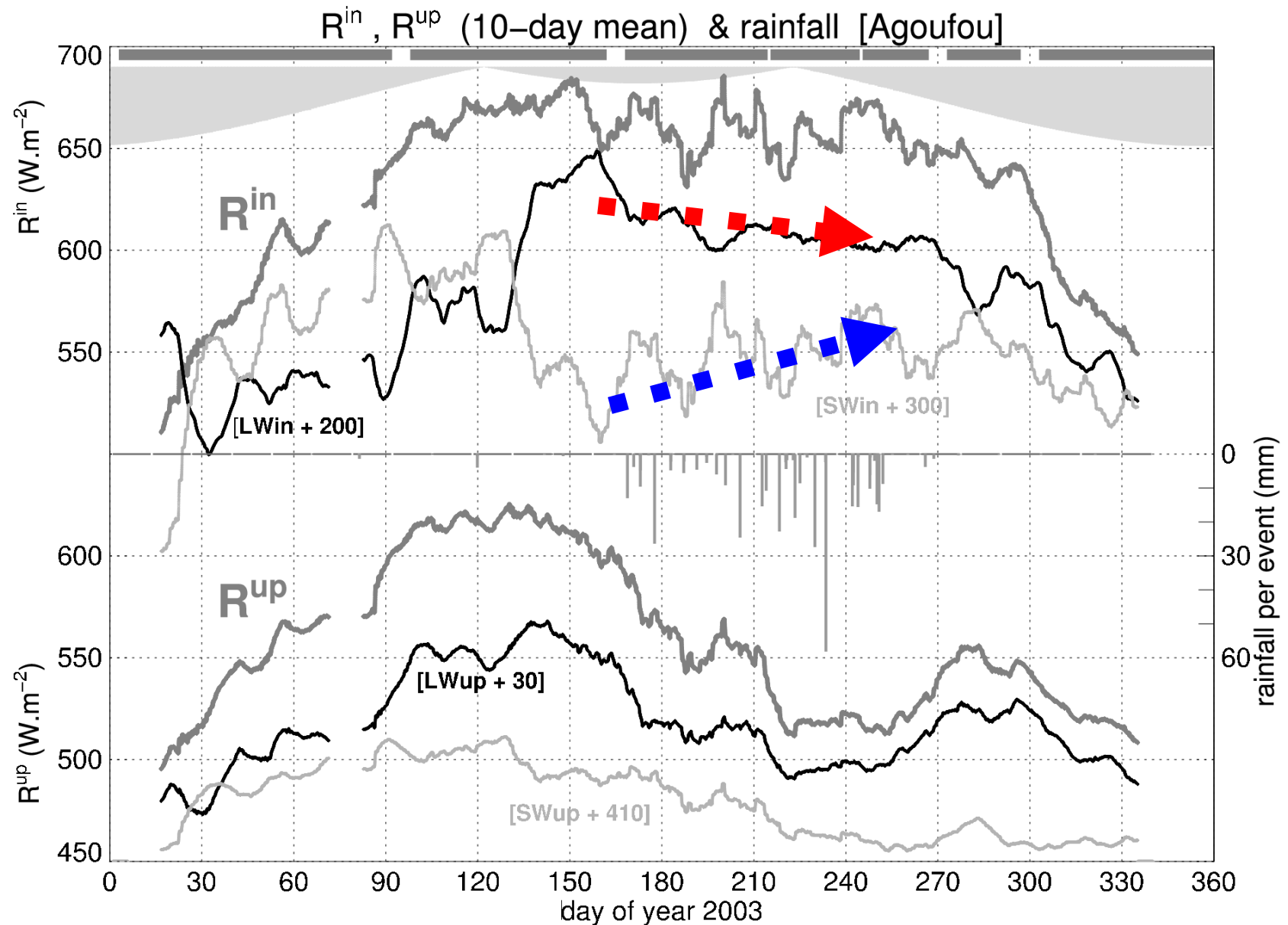
dry season: warm surface & low opacity of the atmosphere
opposite situation during the monsoon

SW^{net} increases from June to mid-Sep (albedo, rad forcing of aerosols/water)

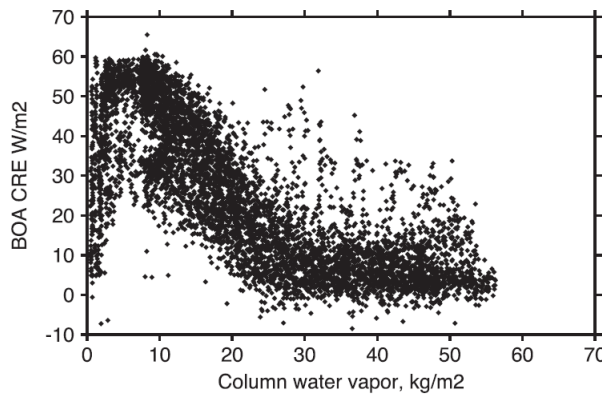
LW^{net} fluctuations mirror those of water vapour

seasonal cycle of surface radiative fluxes

$$R^{\text{net}} = R^{\text{in}} - R^{\text{up}} = (LW^{\text{in}} + SW^{\text{in}}) - (LW^{\text{up}} + SW^{\text{up}})$$



Couplings between cloud LW radiative impact and precipitable water



Stephens et al. (2012)

over Ocean

*cloud radiative impact in the LW at the surface:
sensitivity of to precipitable water*

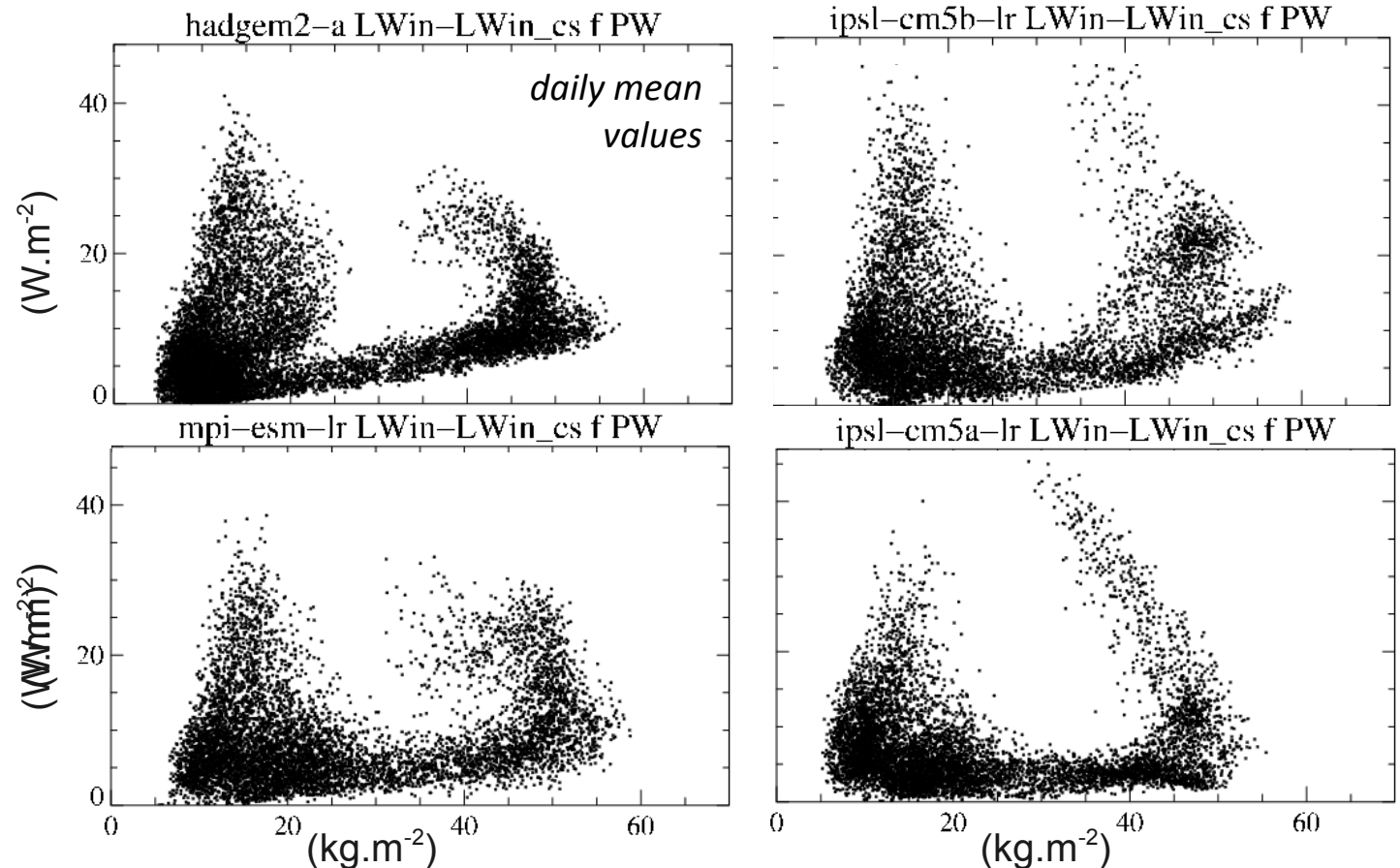
Over The Sahel

MODELS

relationship in
des observations?

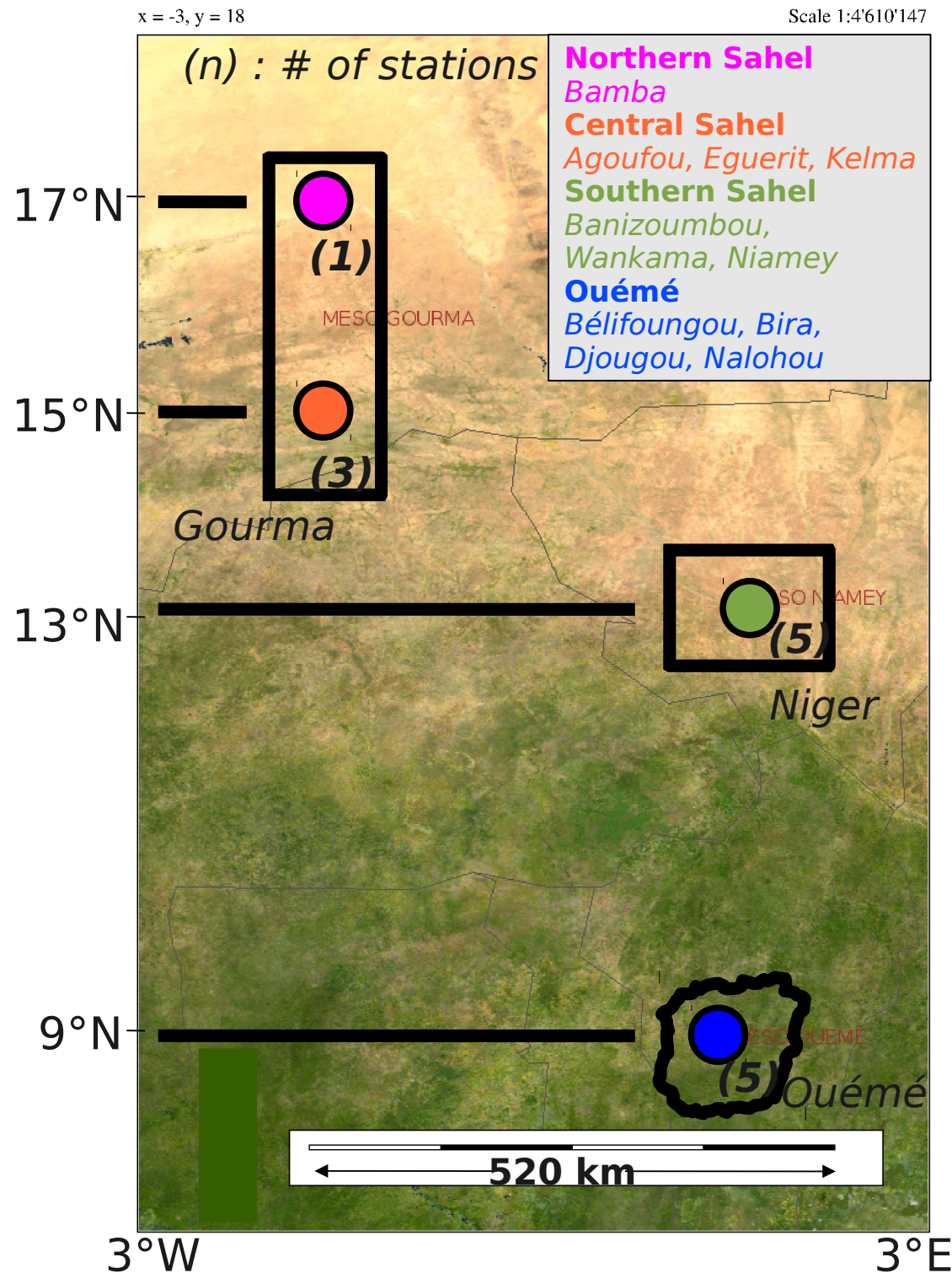
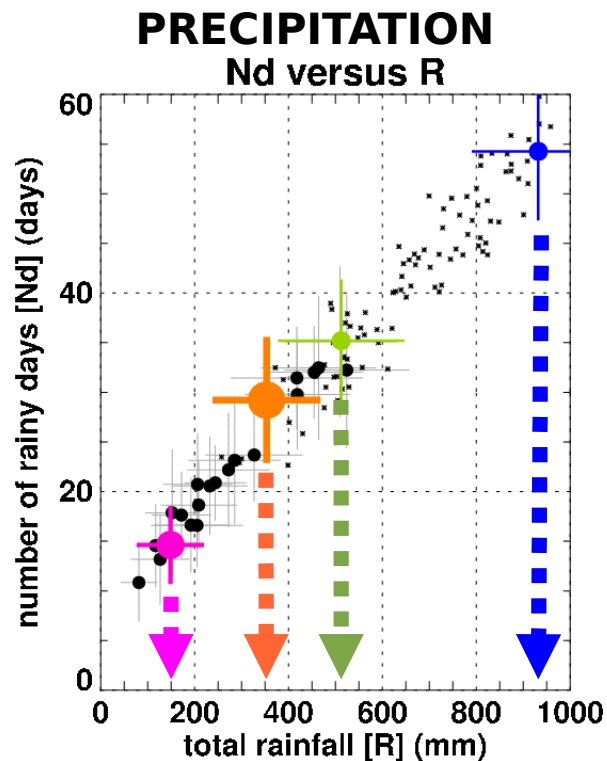
Which link with cloud
type? Cofluctuation at
within the diurnal
cycle?

Work in progress...



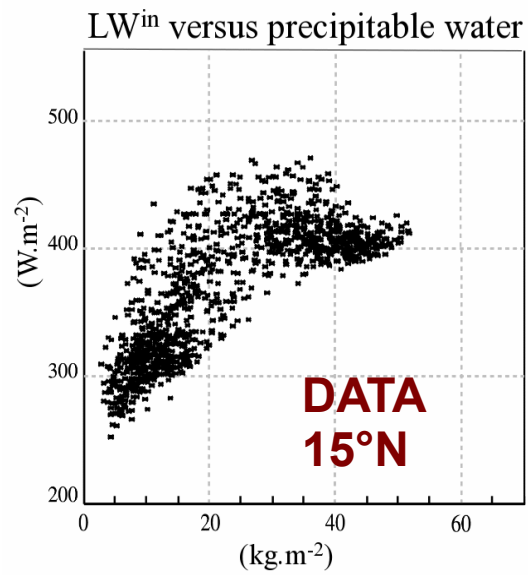
THE AMMA-CATCH MEASUREMENT SITES

Located along a meridional climatological gradient
Over \neq surface/vegetation types

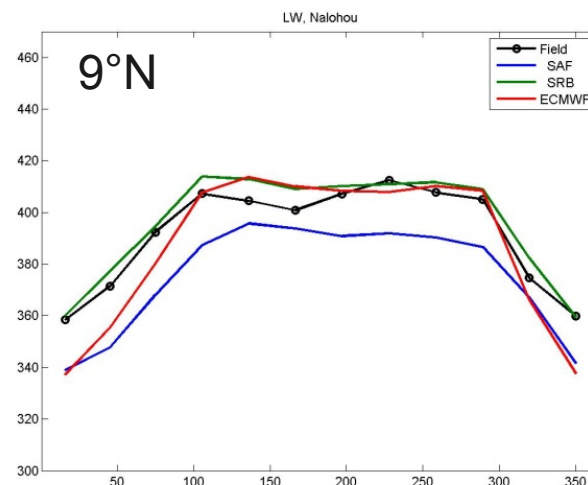
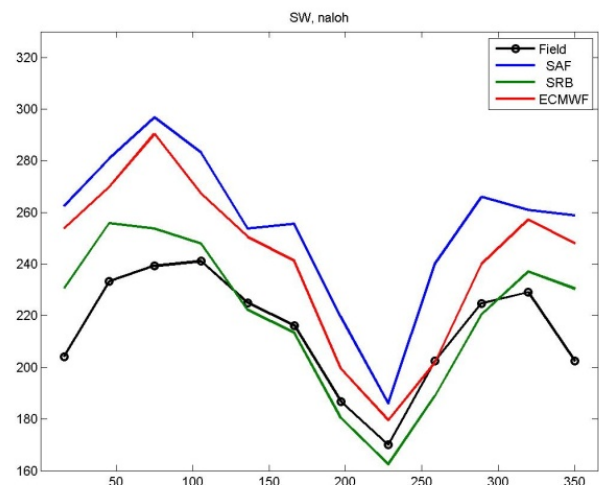
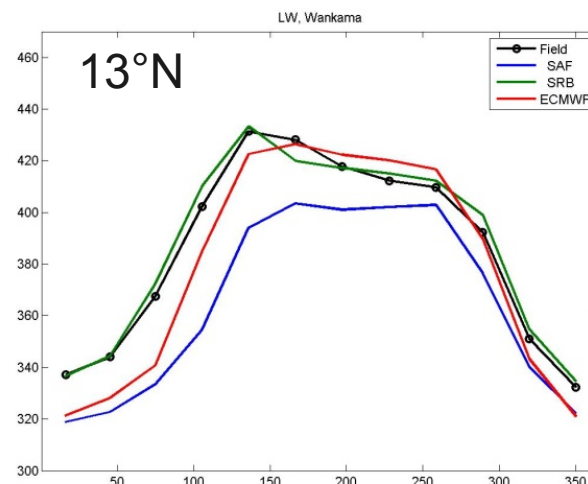
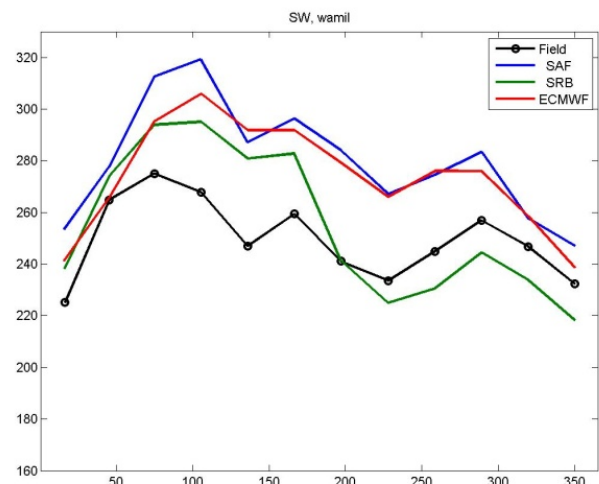
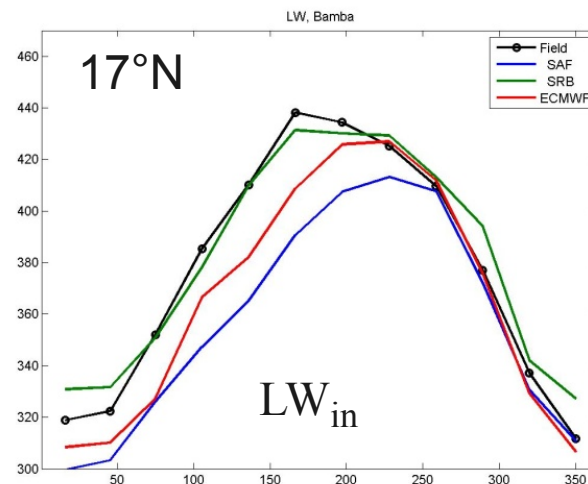
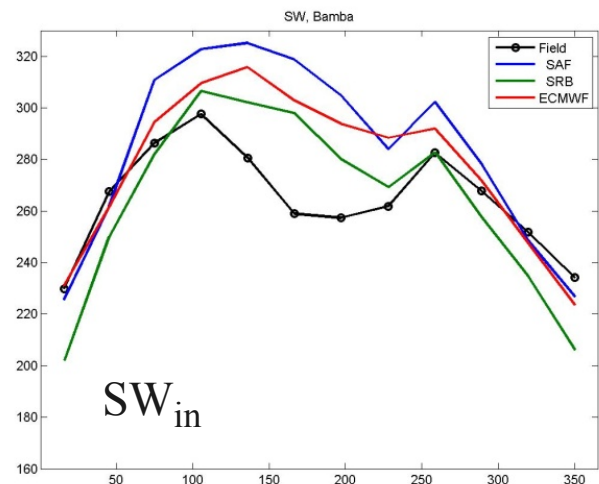


*More about these sites: special issue
Journal of Hydrology (2009)*

Couplings between surface LW_{in} and precipitable water



Estimation Satellite Reanalyses products



*Kergoat
Ramier
et al.*

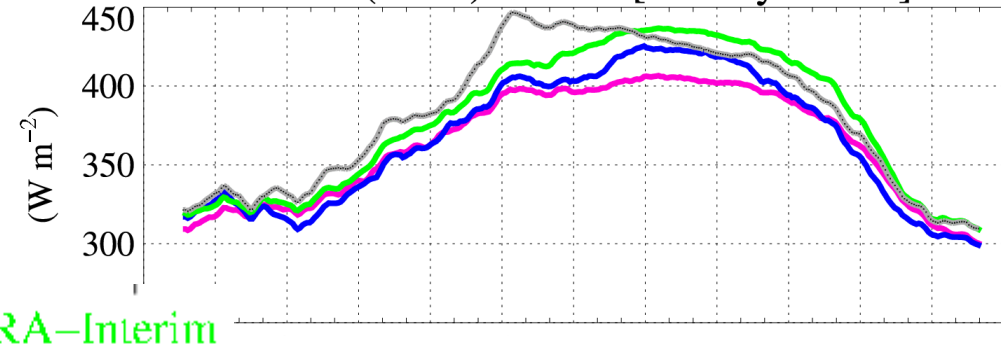
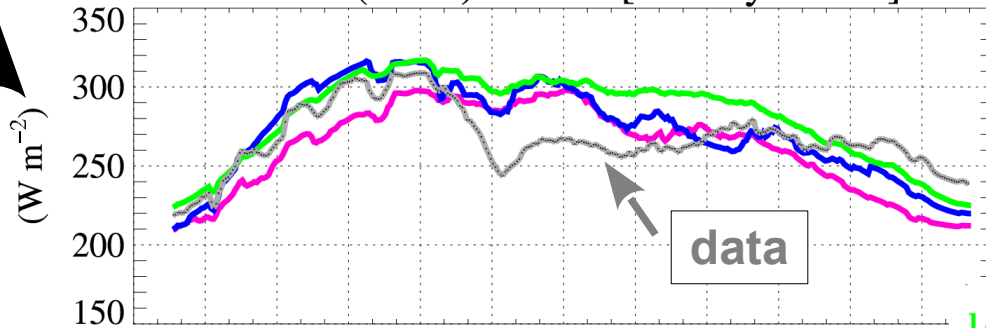
Caution needed with surface radiation reanalyses

SWin

LWin

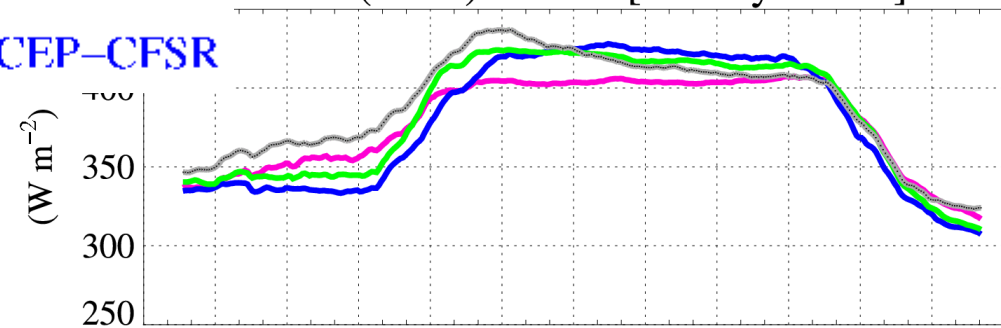
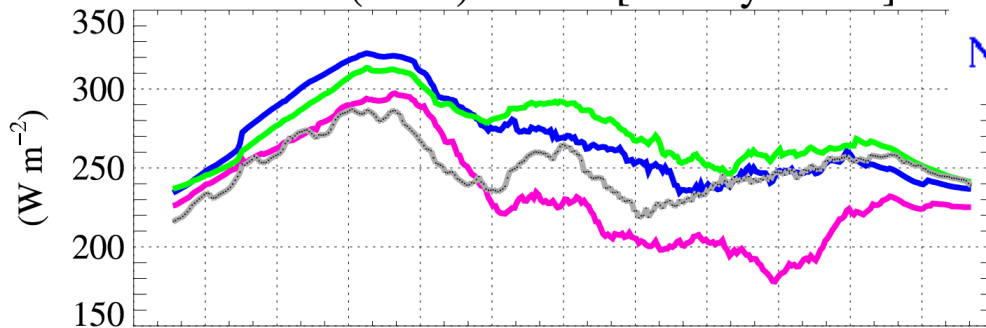
bamba (17°N): SWin [31-day rmean]

bamba (17°N): LWin [31-day rmean]



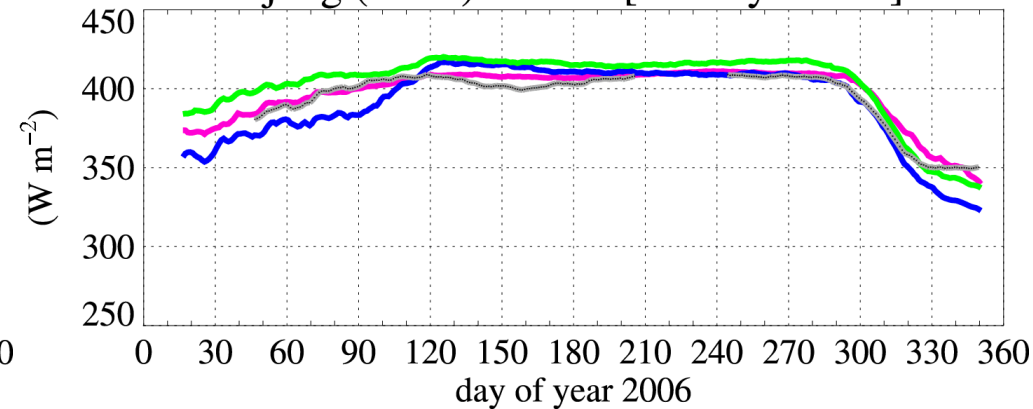
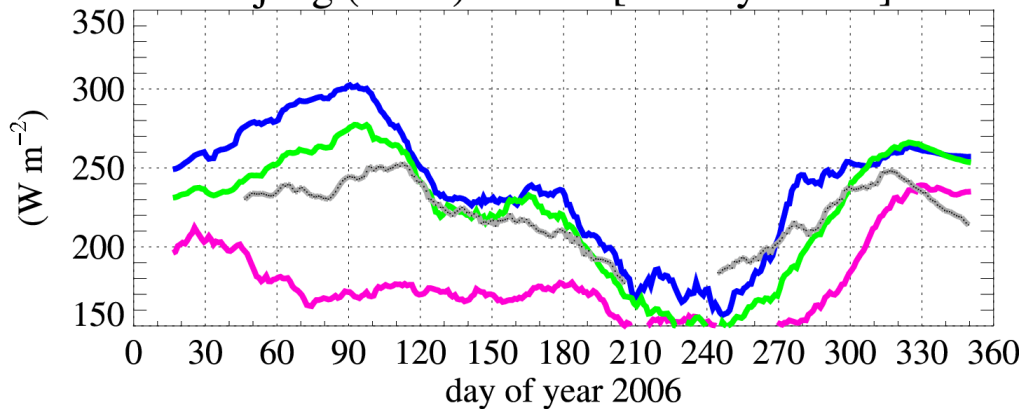
niame (13°N): SWin [31-day rmean]

niame (13°N): LWin [31-day rmean]



djoung (10°N): SWin [31-day rmean]

djoung (10°N): LWin [31-day rmean]



North

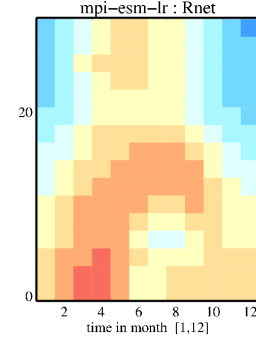
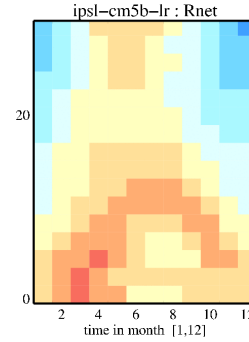
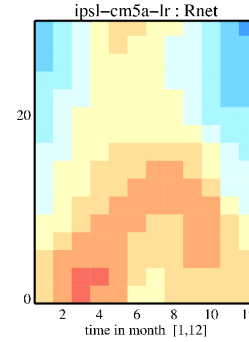
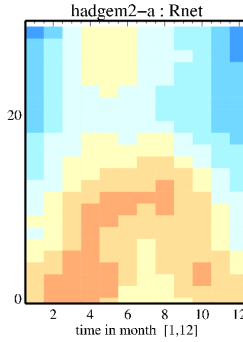
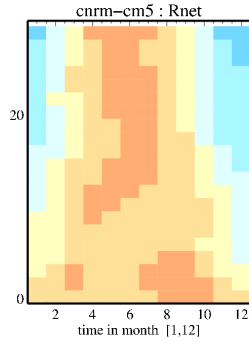
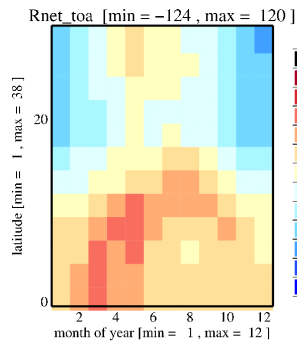
EVALUATION OF CLIMATE MODELS

monthly mean [10°W,10°E], 30 years, CMIP5 amip runs

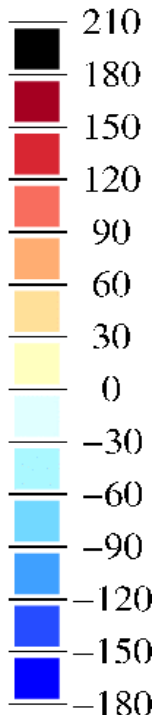
ISCCP

MODELS

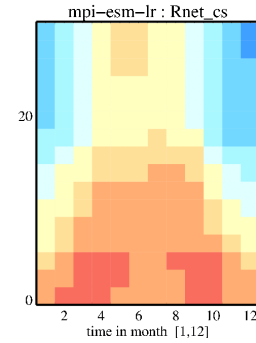
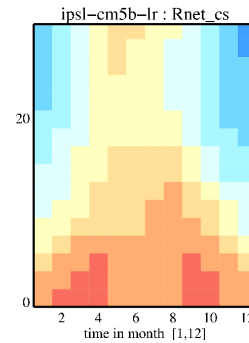
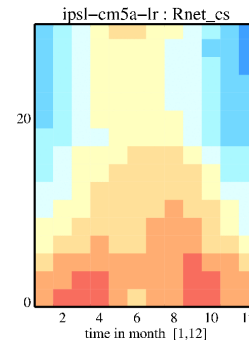
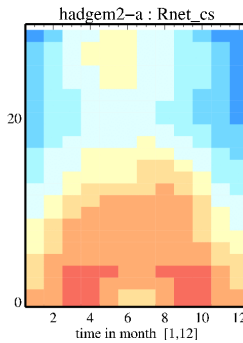
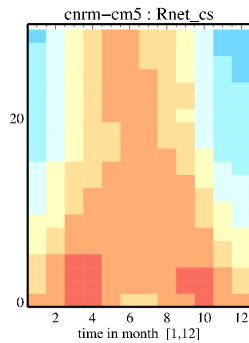
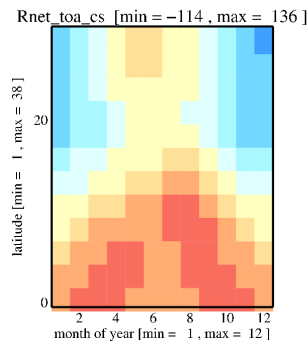
**Rnet
TOA**



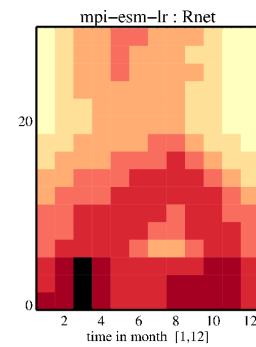
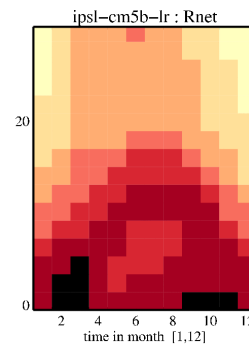
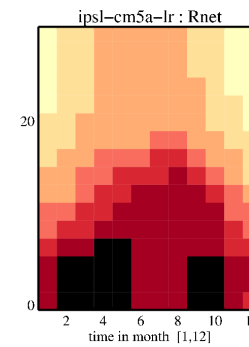
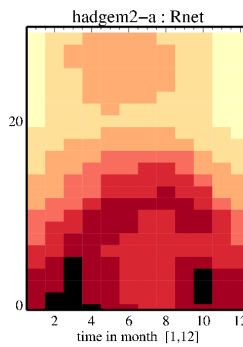
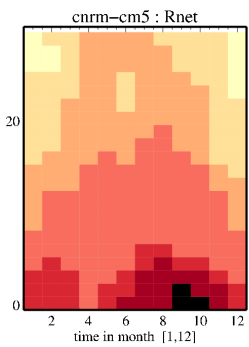
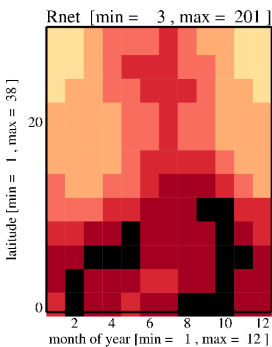
(W/m²)



**Rnet
TOA
clear
sky**



**Rnet
surface**



qualitativement ~ OK, gros soucis quantitatifs

Evaluation of clouds in CMIP5 AMIP runs

Cloud radiative impact TOA and surface, fct (latitude)

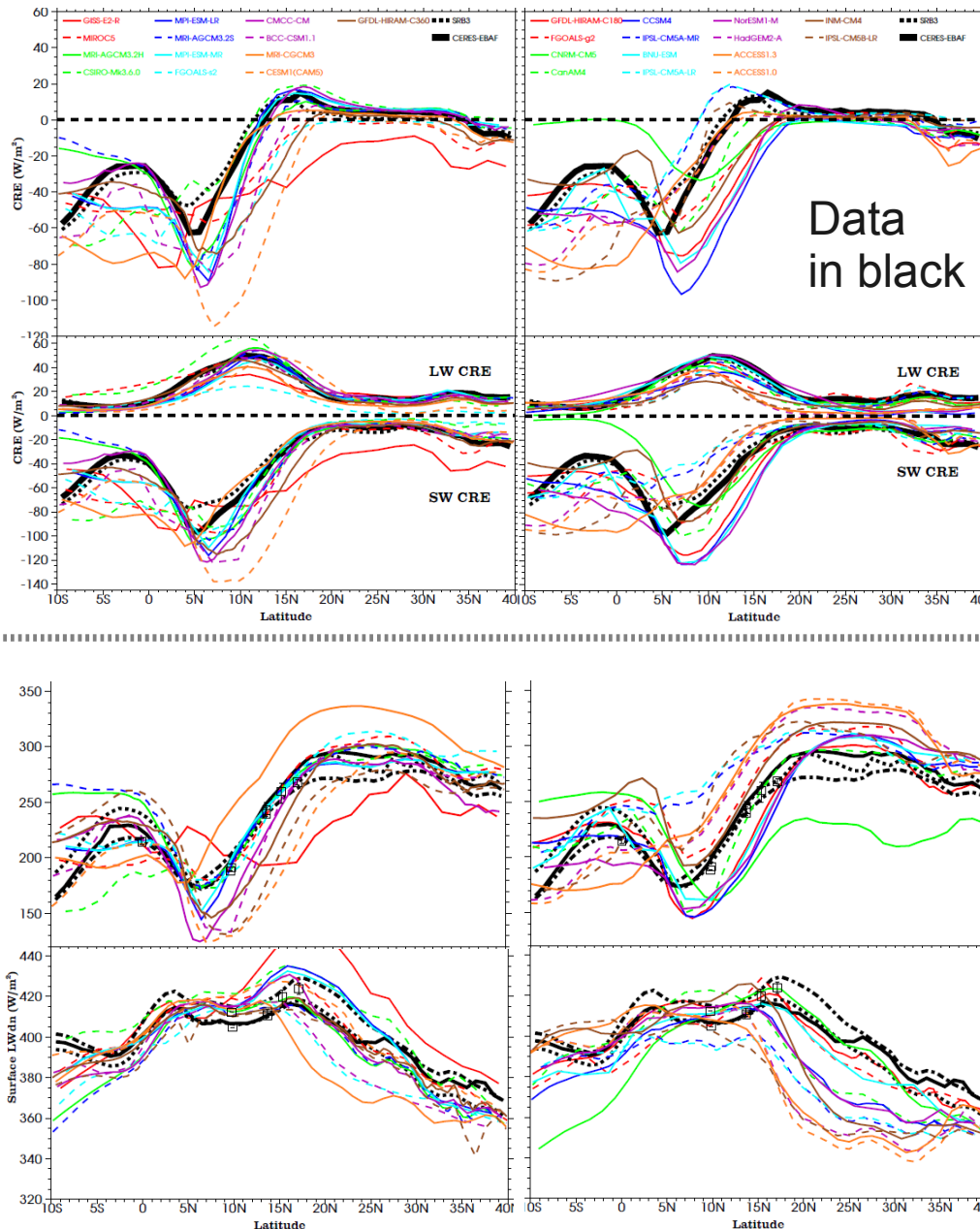
on R_{net} TOA

on OLR

on SW TOA

on SW_{in} sfc

on LW_{in} sfc



Data
in black

Broad features generally captured by models (with season-mean differences of up to several tens of W.m^{-2})

The differences in the latitudinal position of the ITCZ cannot account alone for the large biases in TOA and surface radiative fluxes (several tens on W.m^{-2})

large compensating errors

Roehrig et al. (2013)